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Original research article

# An integrative approach to regional mapping of suitable habitat for the Blanding's turtle (*Emydoidea blandingii*) on islands in Georgian Bay, Lake Huron

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ABSTRACT

Mapping suitable habitat for a species at risk is one of the first steps in a conservation plan. Creating habitat suitability maps can be very challenging when the area of interest is large and located in remote areas where field excursions can be difficult to implement. Such is the case for the Blanding's turtle, a threatened species in Ontario, that live on the Georgian Bay archipelago. With increasing anthropogenic pressures, maps indicating suitable habitat can aid management decisions and prioritize areas for protection. We apply an interdisciplinary approach using traditional field data and generalized linear models to produce high resolution, regional maps which identify suitable habitat for Blanding's turtles throughout the archipelago. We assessed the accuracy of our models using an independent survey dataset of 16 island sites distributed throughout the archipelago, and evaluated models using a reference island as a threshold for determining suitability of survey sites. Islands with higher proportions of wetlands and vernal pools were generally considered to be suitable for Blanding's turtles compared to those with lower proportions. Our findings highlight the importance of both permanent and temporary wet habitats for Blanding's turtles. Based on our final model, approximately 64% of evaluated islands support habitat for Blanding's turtles. Our study is the first to produce detailed habitat suitability maps for Blanding's turtles on the Georgian Bay archipelago. We recommend an integrative approach be applied to create habitat suitability maps for other species at risk in Georgian Bay.



## 1. Introduction

Identifying potential or suitable habitat for species at risk can provide useful information when developing conservation strategies. Habitat suitability models based on environmental variables and habitat classes can be created to predict distribution of important habitats or species occurrence (Ottaviani et al., 2004). Resulting models can guide management plans, identify gaps in distribution, reveal areas with previously undetected populations, and predict distribution changes in response to climate change or land-use alterations (Manel et al., 2001). Development of effective habitat suitability models relies on availability of accurate and up-to-date information on the target species but such information is often limited. In the case of the Blanding's turtle (*Emydoidea blandingii*), conservations plans are empirically derived (The Blanding's Turtle Recovery Team, 2002) and, in Canada, are available for areas where extensive research has previously been conducted

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(e.g. Nova Scotia and Quebec). For Ontario, development of a recovery strategy has been identified as a priority but knowledge gaps exist and additional research is required (Government of Canada, 2015).

Across the species' range, the Blanding's turtle is known to use aquatic habitats such as vernal pools, bogs, marshes, and fens (Rowe and Moll, 1991; Hartwig and Kiviat, 2007; Edge et al., 2010; Markle and Chow-Fraser, 2014), and terrestrial habitats throughout the active season (Ernst and Lovich, 2009). During spring, Blanding's turtles emerge from overwintering habitats such as permanent pools (Ross and Anderson, 1990; Graham and Butler, 1993; Joyal et al., 2001), streams (Ross and Anderson, 1990; Newton and Herman, 2009), marshes (Kofron and Schreiber, 1985; Rowe and Moll, 1991; Edge et al., 2009; Seburn, 2010), and a variety of upland wetlands (Joyal et al., 2001; Edge et al., 2009; Newton and Herman, 2009; Seburn, 2010). During the reminder of the active season, Blanding's turtles have been found to display site fidelity to residence wetlands (Congdon et al., 2011) but utilize a mosaic of aquatic and terrestrial habitats to move among wetlands and access nesting sites (e.g. Standing et al., 1999; Hartwig and Kiviat, 2007; Beaudry et al., 2009 and Markle and Chow-Fraser, 2014). In addition to diverse habitat use, male and female Blanding's turtles may make long distance terrestrial movements (Ross and Anderson, 1990; Rowe and Moll, 1991), suggested to be an important vector for increased gene flow (McGuire et al., 2013); studies have reported males travelling 900 m in early summer (Markle and Chow-Fraser, 2014) and females migrating over 6 km to nest (Edge et al., 2010). Extensive upland movements in combination with varied habitat use requires conservation plans which understand Blanding's turtle response to landscape composition. With the development of habitat suitability models, we can provide a landscape-level perspective on habitat requirements.

In Canada, the Great Lakes/St. Lawrence population of Blanding's turtles is listed as both federally and provincially threatened (COSEWIC, 2005; Government of Canada, 2009). Within the Great Lakes, a population of Blanding's turtles exists on the Georgian Bay archipelago, located in the eastern arm of Lake Huron and designated a world biosphere reserve (UNESCO, 2014). Because Georgian Bay is only 2 h north of Toronto, it is easily accessible to many weekend users and contains the busiest recreational waterway in Canada (Walton and Villeneuve, 1999). Although the archipelago consists of mostly pristine habitat (Cvetkovic and Chow-Fraser, 2011), increasing development pressures threaten species and habitats (Walton and Villeneuve, 1999). Limited data exist because the remote location and large number of islands make it difficult to conduct intensive field studies in the archipelago. Comparison of two Blanding's turtle populations on Canadian Shield, one on an island (protected island, Markle and Chow-Fraser, 2014) and the other on mainland (Algonquin Park, Edge et al., 2010), revealed differences in habitat use and home range size. Selection of ephemeral wetlands was more pronounced in the island population, and average home range sizes were smaller compared to the mainland population (female: 20.5 ha vs. 61 ha; male: 15 vs. 57 ha, respectively; Edge et al., 2010 and Christensen and Chow-Fraser, 2012). Such a comparison of populations living in different parts of Ontario highlights difficulties that may arise when managers develop conservation strategies with data derived elsewhere when no relevant information exists for the system of interest (Hubert and Rahel, 1989). In addition to differences in turtle home range size and habitat use, Georgian Bay is also recognized as the northern range limit for Blanding's turtles (Ontario Government, 2014), and this may have implications for ectotherms that must adapt to cooler temperatures. Therefore, it is important that we develop a habitat suitability model using parameters appropriate to the Georgian Bay landscape, based on data collected only from the Georgian Bay archipelago.

To date, three models have been published for the Blanding's turtle, those of Poynter (2011), Barker and King (2012) and Millar and Blouin-Demers (2012). Millar and Blouin-Demers (2012) used two modelling approaches (boosted regression trees and maximum entropy modelling) to predict habitat suitability for southern Ontario. In their resulting models, Millar and Blouin-Demers (2012) determined that habitat suitability increased with increasing air temperature and wetland area, and decreased with increasing cropland area. Given that cropland is limited only to the southern portion of Georgian Bay, the southern Ontario model may be unable to discriminate between suitable and unsuitable habitat in most of eastern Georgian Bay. Results obtained at a broad provincial scale are particularly useful for evaluating species distribution patterns, but are usually difficult to incorporate into specific conservation or recovery strategies that agencies aim to develop for specific parcels of land Barker and King (2012) developed a parcel-specific model for the Gatineau Park, Quebec. They identified the suitability of individual wetlands for Blanding's turtles; however, transferability of their model to Georgian Bay is limited by inclusion of habitat features that they identified as being important to Gatineau Park, but which do not correspond with features in the Shield landscape of Georgian Bay (Edge et al., 2010; Markle and Chow-Fraser, 2014). A similar approach was used to identify potential Blanding's turtle habitat in Ohio (Poynter, 2011), although vegetation categories used were too coarse to be applied to the Georgian Bay context. Overall, it appears that the published models of habitat suitability are not directly applicable or transferable to the Georgian Bay archipelago.

The primary objective of our study is to develop a habitat suitability model for the Blanding's turtle specifically for the Georgian Bay archipelago, so that suitable habitat can be identified and marked for protection in conservation plans before habitat is degraded or developed. We assume that radio tracking data for a population of Blanding's turtles on a protected island can be used to indicate suitable habitat. Therefore, we use landscape composition of the reference island to map habitat suitability of other islands within the archipelago. Secondly, we investigate changes in model accuracy when habitat data are extracted with different buffers (i.e. circular or grid). Specifically, we hypothesize that the approach which more specifically quantifies habitat used by radio-tracked turtles (circular buffer centred on locational point) will be more accurate in determining important landscape components compared to a more general approach (grid overlaid on the study area). The resulting model can produce maps at the regional scale for use in conservation and management strategies. We use an interdisciplinary approach that combines field data, remote sensing, and statistical modelling to produce spatially explicit

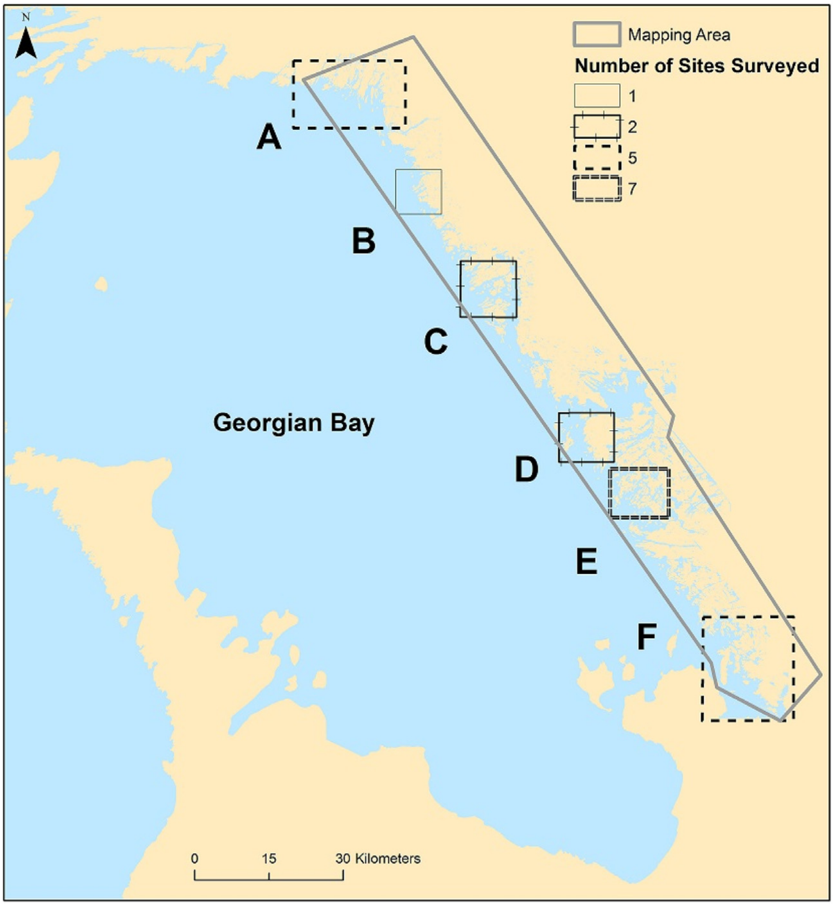


**Fig. 1.** Mapping area for determining suitable Blanding's turtle habitat along the eastern shoreline of Georgian Bay. Distribution and number of external survey zones are labelled A–F.

statistical models to identify and map key habitats for the Blanding's turtle over a large region, and should advance efforts to develop effective management plans for Blanding's turtles throughout the biosphere reserve.

## 2. Methods

### 2.1. Study area

Our area of interest includes all islands spanning the eastern shoreline of Georgian Bay from the French River to Severn Sound (Fig. 1). Specifically, the study area encompasses island habitat in the Parry Sound Ecodistrict, which is found in the Georgian Bay Ecoregion in the southern portion of the Ontario Shield Ecozone (Crins et al., 2009). Restricting the model to an ecodistrict eliminates major landscape, habitat and geological differences which influence vegetation (Ontario Government, 2007) and may result in differences in habitat use by turtles. The Parry Sound Ecodistrict currently supports relatively high biodiversity, including 11 reptile species at risk; due to increased cottage development and recreational boating, some habitats are being threatened (Bywater, 2013), although not to the same extent as are wetlands and natural habitats south of the Canadian Shield, that receive much greater negative impact from urbanization and agricultural development (Environment Canada, 2013).

### 2.2. Habitat classification

To map suitable habitat, we require both input data (spatial layers of different habitat types) and a suite of spatial and statistical tools (see Fig. 2). We created habitat layers prior to model development and included all available habitat types in Georgian Bay as predictors in our models: forest, wetland, vernal pool, rock, and open water (Table 1; Markle and Chow-Fraser, 2014). We decided to keep wetland as a broad category rather than sub-dividing since Blanding's turtles use a variety of wetlands at the home range scale (Markle and Chow-Fraser, 2014) and use of a particular wetland type may depend on its availability within an island. Other than vernal pools, all habitat types could be classified from satellite image data;

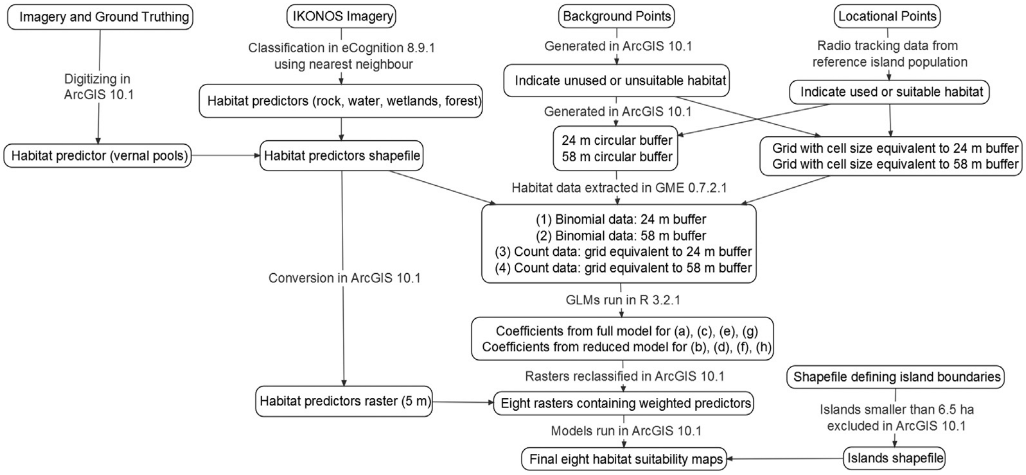


**Fig. 2.** Flow chart outlining methodology applied to create habitat suitability maps.

**Table 1**
Definitions of habitat types following the Canadian National Wetlands Classification System (Warner and Rubec, 1997; Markle and Chow-Fraser, 2014).

| Habitat type | Brief description |
|---|---|
| Wetland | Contains water long enough to promote aquatic processes. We classified fens, bogs, swamps, marshes as wetlands in our study area. |
| Open water | Large body of open water where the maximum depth is $>$ 5 m. |
| Forest | Coniferous forest with needleleaf species such as white pine (*Pinus strobus*) and hemlock (*Tsuga* spp.). Hardwood forest with species such as sugar maple (*Acer saccharum*) and beech (*Fagus* spp.). |
| Rock | Rocky outcrops characteristic of the Canadian Shield. |
| Vernal pool | Temporary pools that are only seasonally flooded. Also called ephemeral pools. |

the vernal pools, however, could not be classified from satellite image data and required manual delineation in ArcGIS 10.1 (ESRI, California, USA). We used a combination of 2008 spring orthophotos (30 cm resolution), Google Earth (Digital Globe) and ground truthing to map all vernal pools on the islands. We digitized a feature as a vernal pool if we identified a small temporary pool (usually isolated within a forest matrix) typically visible only in images acquired during springtime. Temporary pools were often located around permanent upland wetlands or in forested areas.

To create the layer of forest, wetland, rock and open water, we used IKONOS imagery (Geoeye, Dulles, VA, USA), acquired during 2002 (22 scenes), July 2003 (19 scenes), July and August 2005 (3 scenes) and July 2008 (1 scene). All images were cloud-free, multispectral (red, green, blue and near infrared), pan-sharpened and radiometrically corrected with a resolution of 1 m. We classified IKONOS images in eCognition Developer 8.9.1 (Trimble, Munich, Germany) using a nearest neighbour (NN) approach at the image object level. Object-based image classification provides benefits over pixel-based classification such as including object shape and size (Blaschke, 2010) and has been used to classify habitat for Blanding's turtles in Quebec, Ontario (Barker and King, 2012). The NN approach combines multiresolution segmentation and supervised classification to identify object class based on selected training objects (Wang et al., 2004; Grenier et al., 2007). This approach requires a set of defined features to create a group of training and testing objects. Before training and testing objects were selected, we developed an initial rule set to classify major bodies of water and to separate upland areas for further segmentation. Once upland areas were segmented, we selected the training group to be representative of the range of objects present in the scene which allows for a more accurate classification. Since rule set transferability has been found to vary in its accuracy (Rokitnicki-Wojcik et al., 2011), each scene was individually classified with the NN approach. We randomly selected 10 of the 45 classified scenes to determine habitat classification accuracy. For each scene a stratified random sampling method was implemented similar to that of Grenier et al. (2007). A 1 km $\times$ 1 km grid was placed over the scene and points were randomly generated in each grid. A total of 50 objects per class were verified, excluding objects used for training. Verified objects (testing group) were then used to compute error matrices and kappa index of agreement (KIA). The kappa index measures the difference between agreement and agreement by chance (Viera and Garrett, 2005). It is measured on a scale from 0 to 1, where 1 is perfect agreement and 0 is the outcome expected by chance.

All habitat classes were exported from eCognition 8.9.1 into ArcGIS 10.1 and individual islands in the archipelago were manually checked for boundary accuracy. All habitat classes were then converted to a 5 m cell size raster.

### 2.3. Statistical analyses

We used locations of Blanding's turtle collected in 2011 and 2012 (obtained by radio-tracking and GPS devices; see details in Markle and Chow-Fraser, 2014) on a protected island (considered our reference site) in southeastern Georgian

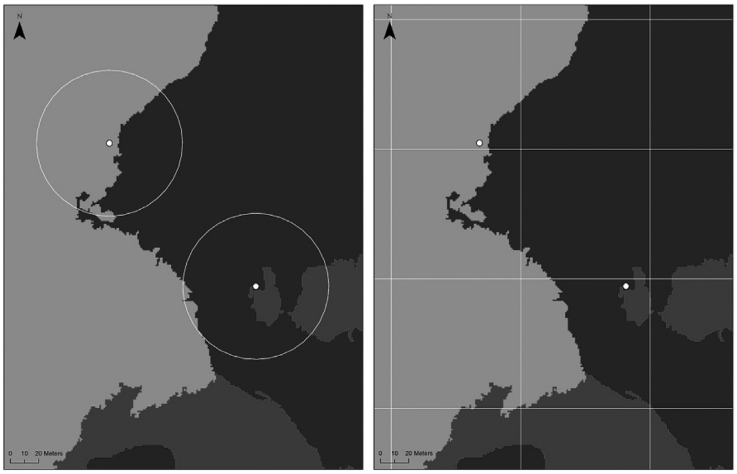


**Fig. 3.** The circular buffer approach extracts habitat variables centred on the location of interest (Left panel). The grid approach extracts habitat variables from cells containing locations (Right panel). Notice how the locations in both panels are the same, yet habitat variables extracted differ based on the approach used.

Bay to quantify suitable island habitat. In total, location data from 15 adult Blanding's turtles (8 males, 7 females, 509 locations) were used to quantify used or suitable habitat. Turtles were radio tracked at least once per week during the active season (April–September) and hibernation locations were collected in November 2011, February 2012 and February 2013. To quantify unused or unsuitable island habitat, we randomly generated 1018 background locations in ArcGIS 10.1 that did not overlap with turtle locations. We included both suitable and unsuitable locations because modelling techniques that used both data sources have been shown to outperform those using presence-only data (Elith et al., 2006; Elith and Graham, 2009). To extract habitat variables, we used the circular buffer approach and the grid approach (Fig. 3). For both methods, data were extracted as cover percentage in Geospatial Modelling Environment 0.7.2.1 (Beyer, 2014). For the circular buffer method, we extracted habitat variables within two circular buffers (24 and 58 m) surrounding turtle and background locations; distances were chosen to represent the minimum and maximum distances travelled by turtles on a daily basis in our reference site (Markle and Chow-Fraser, unpublished).

For the grid method, we overlaid a grid with cell size equivalent to circular buffer area. We extracted habitat variables from cells containing turtle or background locations.

We used habitat variables (forest, wetland, vernal pool, rock, and open water) as predictors in 8 generalized linear models run in R 3.2.1 (R Core Team, 2015) to determine the suitability of other islands in Georgian Bay. In a generalized linear model, the expected value of $Y(mu_y)$ is linearly related to the response variables ($X_i$) through a link function ($f(x)$); so that:

$$f(mu_y) = b_0 + b_1X_1 + b_2X_2 + \cdots + b_kX_k.$$

We chose generalized linear models because they are easily applied to new data to make predictions (Guisan and Zimmermann, 2000; Early et al., 2008), are better for datasets including both detections and non-detections (Guisan et al., 1999; Elith and Graham, 2009), and are frequently used in species distribution modelling (Guisan and Theurillat, 2000; Randin et al., 2006). Since data for the buffer method were expressed in binary format (0 or 1), we ran generalized linear models (logit link function: $f(x) = \log(x/1 - x)$). We ran negative binomial generalized linear models (log link function: $f(x) = \log(x)$) for the grid method since data were expressed as counts (many zeros, various integers). In models using the buffer method, background data were weighted to have equal prevalence to turtle locations.

Of the 8 models, models (a), (c), (e), and (g) include all predictors for each approach (full model with all predictors), while models (b), (d), (f) and (h) are the models with the lowest corrected Akaike Information Criterion (AICc) for each approach (reduced model; Fig. 2). We selected an information-theoretic tool as they tend to be preferred to methods such as stepwise regression (Guisan et al., 2002; Bolker et al., 2009) and the corrected AIC since it is advantageous in small-sample applications (Burnham and Anderson, 2002).

### *2.4. Spatial analyses*

Our study area contained 16,586 islands, many of which are small and have mostly rocky habitat. Since the smallest Blanding's turtle home range in our reference population was 6.5 ha (Christensen and Chow-Fraser, 2012), we eliminated all rocky islands $<$ 6.5 ha from further analyses since this is likely smaller than the minimal area required by the Blanding's turtle on an island in the archipelago. Although Blanding's turtles home ranges have been estimated for other populations (e.g. Hamernick, 2000; Piepgras and Lang, 2000; Innes et al., 2008; Schuler and Thiel, 2008; Edge et al., 2010 and Millar and Blouin-Demers, 2011), estimates can vary among studies due to sample size, duration of study and most importantly differences in habitat (Cagle, 1944; Bury, 1979). Therefore, setting the constraint using home range estimates from a population within our study area provides the most comparable estimate. Of the 16,199 excluded islands, majority were below 0.25 ha ($\mu = 0.3$ ha $\pm$ 0.006) and unlikely to support Blanding's turtles. The remaining 387 islands in the dataset had the best chance of containing potential Blanding's turtle habitat, and we applied a zonal statistics approach to obtain an overall suitability score for each of the islands. The 8 models run in R 3.2.1 (Fig. 2) yielded statistical outputs that were applied in ArcGIS 10.1 to produce spatial representations of those equations. Since our reference island is known to support Blanding's turtles, the degree of similarity of other islands to our reference site was used to indicate their suitability as Blanding's turtle habitat.

### 2.5. Model evaluation

Testing data were required to determine the relative accuracy of each model's ability to determine potential or suitable habitat. Although it is more common to use data partitioning or resampling techniques to derive the testing dataset rather than using an independent dataset, the latter will yield more robust measures (Verbyla and Litvaitis, 1989; Fielding and Bell, 1997). We therefore conducted field surveys at 10 additional sites and obtained sighting data for 12 sites from local citizens (Fig. 1). Citizen sighting data were only used if we could confirm species identification with photographs. We are withholding the exact location of specific sightings to protect Blanding's turtles and instead use general survey zones. Sites were chosen in similar fashion to an equal-stratified design (Hirzel and Guisan, 2002) where shoreline was divided into regions and we attempted to randomly select sites based on our ability to access selected islands. Surveys were conducted in 2013 and 2014 during the summer months on sunny, calm days when possible. Each site was surveyed either by foot or canoe with the aid of binoculars and was searched for 12 person hours. All species of turtles encountered were recorded as either detected or undetected.

We used a threshold-based evaluation method to assess the appropriateness of using landscape composition of a reference island to map habitat suitability of other islands in the archipelago. For each model, the score assigned to the reference island is used as the threshold value. The threshold value is then used to evaluate whether or not external survey sites should be able to support Blanding's turtle and accuracy of each evaluation is assessed with field information. For example, for each model, we calculated the suitability scores for all external survey sites and our reference island. We then used the score for the reference island as a threshold value. When validating the model with external data, sites with scores that were greater than the threshold value were considered to be suitable and conversely, sites with scores less than threshold value were considered to be unsuitable. Models which correctly classified external survey sites in comparison to the reference island score were retained. Models that failed to correctly classify external survey sites were subsequently eliminated. Although threshold-based model evaluation is often used to classify areas into categories of either suitable or unsuitable habitat (Bean et al., 2012), we show final maps using continuous suitability predictions (from 0 to 1) and use thresholds only for evaluation.

## 3. Results

### 3.1. Habitat classification

Our habitat classification of the land cover layer had a mean overall accuracy of 92.3% $\pm$ 1.68 with an average kappa index of agreement of 0.88 $\pm$ 0.0198. Therefore, we were confident in using the resulting classification to conduct the habitat suitability mapping.

### 3.2. Statistical analyses

We ran 8 different models using a generalized linear model in R 3.2.1. In the full models, rock, forest, and open water were negative predictors of habitat suitability whereas wetland and vernal pools were positive predictors (Table 2). In reduced buffer approach models (b and d), forest was dropped at both scales. In reduced grid approach models (f and h), vernal pool was dropped at both scales. At the smaller spatial scale, reduced models that were created with either approach did not include rock as a predictor (d and h). For models using the buffer approach, wetland was the largest positive predictor of habitat suitability, followed by vernal pools. On the other hand, for models using the grid approach, vernal pool was the largest positive predictor of habitat suitability in model (e), and wetland was the primary predictor in models (g) and (h).

For each predictor, we individually plotted estimated marginal means which indicated mean response while holding other variables in the model at a constant value (Fox, 2003; Table 2). Although we created one set of plots for each dataset, we only show plots using the 58 m buffer, full model dataset (model (a)) because all results were similar (Fig. 4). Suitability of an island tended to decrease with proportionate increase in forest, open water and rock; on the contrary, suitability increased for islands that had a percentage increase in amount of wetland and vernal pools.

When selecting our reduced models (models b, d, f, h), there were instances where the top models had comparable AICc values. We chose to use AICc to select the reduced model; however, uncertainty exists in any selection process. Although still debated (Burnham et al., 2011; Richards et al., 2011), models with an AICc difference of less than 2 are considered as

**Table 2**
Coefficients and 95% confidence intervals of habitat predictors for models (a) through (h) as determined in R 3.2.1.

| Model ID | Method | Size | Model | Intercept | Habitat predictor | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Rock | Forest | Wetland | Open water | Vernal pool |
| (a) | Buffer | 58 | Full | 0.737 | −0.002 (−0.17, 0.17) | −0.026 (−0.19, 0.14) | 0.070 (−0.10, 0.24) | −0.039 (−0.21, 0.13) | 0.057 (−0.12, 0.24) |
| (b) | Buffer | 58 | Reduced | −1.893 | 0.024 (0.01, 0.04) | n/a | 0.096 (0.08, 0.11) | −0.013 (−0.02, −0.00) | 0.083 (0.01, 0.15) |
| (c) | Buffer | 24 | Full | 1.092 | −0.016 (−0.14, 0.12) | −0.027 (−0.15, 0.10) | 0.059 (−0.07, 0.18) | −0.038 (−0.16, 0.09) | 0.026 (−0.11, 0.16) |
| (d) | Buffer | 24 | Reduced | −1.479 | n/a | n/a | 0.083 (0.07, 0.09) | −0.011 (−0.02, −0.00) | 0.051 (0.00, 0.10) |
| (e) | Grid | 58 | Full | 7.128 | −0.065 (−0.63, 0.50) | −0.098 (−0.67, 0.47) | 0.010 (−0.56, 0.58) | −0.111 (−0.68, 0.46) | 0.078 (−0.50, 0.65) |
| (f) | Grid | 58 | Reduced | 14.718 | −0.140 (−0.23, −0.05) | −0.174 (−0.27, −0.08) | −0.065 (−0.16, 0.03) | −0.187 (−0.28, −0.09) | n/a |
| (g) | Grid | 24 | Full | −1.907 | −0.009 (−0.21, 0.19) | −0.021 (−0.22, 0.18) | 0.055 (−0.14, 0.25) | −0.036 (−0.23, 0.16) | 0.024 (−0.17, 0.22) |
| (h) | Grid | 24 | Reduced | −2.631 | n/a | −0.013 (−0.02, 0.00) | 0.062 (0.05, 0.07) | −0.030 (−0.04, −0.02) | n/a |

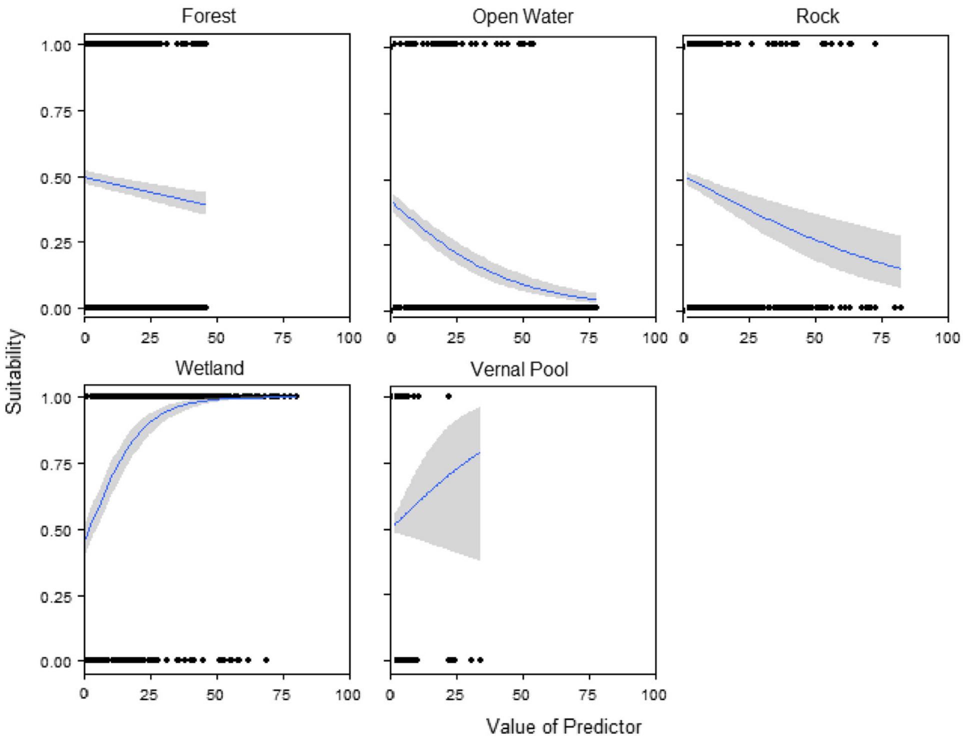


**Fig. 4.** We plotted estimated marginal means for each predictor individually using the binomial dataset with a 58 m circular buffer (Dataset 2; see Fig. 2). Plots were created for each predictor while holding other predictor variables at a constant mean value. Response is shown with 95% confidence intervals. The *x*-axis is the value of the predictor and the *y*-axis is on the probability scale. The points distributed along 0 and 1 of the *y*-axis are the distribution of the raw data used to produce plots.

good as the 'best' model (Symonds and Moussalli, 2011). In situations where ΔAICc is less than 2, models are sometimes averaged together to create a new 'best' model (e.g. Rice et al., 2013), but due to our compositional dataset, averaging was not a feasible option (see Cade, 2015). Instead, we determined our reduced models (models b, d, f, h) as those with the lowest AICc and relied on our external dataset to test the spatial accuracy of all 8 models to determine the final ('best') model for our intended mapping application. Since we do not use our final model to make statistical predictions, but rather a spatial mapping of suitable habitat, our approach should be valid.

### 3.3. Spatial analyses and model evaluation

We confirmed presence of Blanding's turtles at 7 of our 22 external sites (Table 3). During field surveys, we also encountered additional turtle species such as spotted turtles (*Clemmys guttata*), midland painted turtles (*Chrysemys picta marginata*), snapping turtles (*Chelydra serpentina*), Northern map turtles (*Graptemys geographica*) and musk turtles (*Sternotherus odoratus*; Table 3). Since all surveyed islands were located on the Canadian Shield, have minimal human disturbance, and were distributed throughout the eastern shoreline of Georgian Bay, we are confident in extrapolating our model results to the entire archipelago (Fig. 1; Hirzel and Guisan, 2002 and Vaughan and Ormerod, 2005).

We applied all models in ArcGIS 10.1 to obtain predicted suitability scores for each island in our study site. Of our 22 external validation sites, 7 were eliminated based on the minimum size constraint (<6.5 ha) or because they were deemed to be located too close to the mainland to function as an "island". After exclusions, we had 15 sites remaining to assess model accuracy. While the use of field data for model evaluation is considered rigorous (Verbyla and Litvaitis, 1989), logistics surrounding island sampling limited our ability to survey each island multiple times, even though that is often desirable. Despite this drawback, our sampling protocol allowed us to detect Blanding's turtles and therefore we deem this to be sufficient for purposes of model evaluation. We used the calculated score for our reference island as the threshold for determining the ability of each model to classify external validation sites. Models (c), (d) and (g) were eliminated because external sites were incorrectly classified based on the corresponding threshold value. Model (e) and (f) successfully classified suitable sites, but incorrectly classified unsuitable sites and were therefore eliminated. Models (a), (b) and (h) (Fig. 5) all correctly classified suitable sites and the highest number of unsuitable sites, but also classified 4 sites as suitable even though we did not detect Blanding's turtles there during our surveys. Of the models with the highest classification accuracy, model (a) and (b) estimated that 64% of evaluated islands provided suitable habitat for Blanding's turtles, whereas model (h) only estimated 60% of islands to be suitable. Although only 60%–64% of evaluated islands were considered suitable, this

**Table 3**
Survey results from each island are reported by corresponding survey zone (see Fig. 1). If a turtle species was detected, it is indicated with an '×'.

| Site number | Zone ID | Turtle species | | | | | |
|---|---|---|---|---|---|---|---|
| | | Blanding's turtle | Spotted turtle | Northern map turtle | Musk turtle | Snapping turtle | Midland painted turtle |
| 1 | A | | | | | × | |
| 2 | A | | | | | | |
| 3 | A | | | | | | × |
| 4 | A | | | | | | |
| 5 | A | × | | | | | |
| 6 | B | × | | | | | |
| 7 | C | × | | | | | × |
| 8 | C | | | | | | |
| 9 | D | | | | | × | × |
| 10 | D | | | | | | |
| 11 | E | | | × | × | | |
| 12 | E | | | × | | | |
| 13 | E | | | × | | | |
| 14 | E | × | | | | | |
| 15 | E | × | | | | | |
| 16 | E | | | | | | |
| 17 | E | × | | | | | |
| 18 | F | | | | | | |
| 19 | F | | × | | | | |
| 20 | F | × | | × | | | |
| 21 | F | | | | | × | × |
| 22 | F | | | × | × | | × |

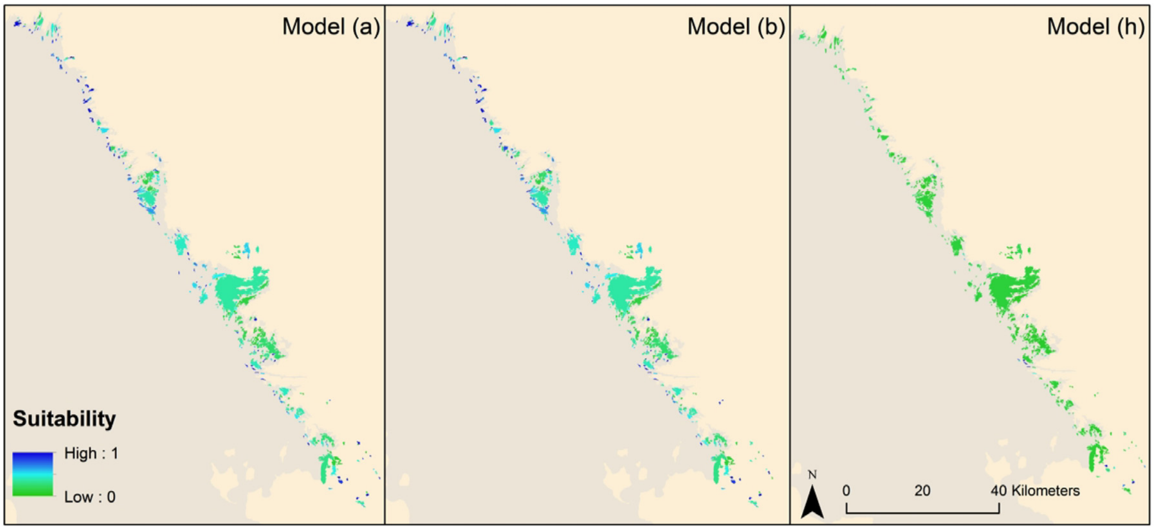


**Fig. 5.** Comparison of 3 final models (see Table 2 for corresponding predictor coefficients).

comprised 85%–90% of the total area in this study. Model (a) and (b) identified 90% and 89% of total area evaluated as suitable habitat for the Blanding's turtles, respectively; whereas, model (h) identified 85% as suitable.

## 4. Discussion

When we visually compared the 3 habitat maps (a, b and h) that correctly classified external survey sites, we observed differences among them (Fig. 5). We ran models (a) and (b) using data extracted with a 58 m buffer. While model (a) included all predictors, model (b) included only significant predictors (i.e. forest was dropped). Both models (a) and (b) yielded similar scores for islands; however, model (b) discriminated between islands with a smaller percentage of wetlands from those that had a high percentage of wetlands by giving them lower and higher scores, respectively. Therefore, we rank model (b) more highly than we do model (a). By comparison, model (h) included only forest, wetland and open water, but the data were extracted from a grid with size equivalent to the area of a 24-m buffer. Overall, model (h) was very conservative and more likely to make errors of omission where an island is given a low suitability score even though the target species is found there.

A conservative model, like model (h), is more likely to omit important islands that support suitable habitat for Blanding's turtles, and lack of sensitivity (with most scores approaching zero) compared to other models make it less desirable for conservation purposes (Fig. 5). Therefore, we ranked model (h) which only uses percent forest, wetland and open water to assess island suitability lower than model (b) which uses percent wetland, open water, vernal pool, and rock because it more accurately classified island suitability.

Our final habitat suitability model (b) indicates that approximately 64% of the evaluated islands or 89% of the total mapped area in the archipelago is suitable for Blanding's turtles. Our final model is consistent with large-scale modelling efforts of Ontario (Millar and Blouin-Demers, 2012), where Georgian Bay was consistently associated with higher habitat suitability scores than were sites in southern Ontario. Since our model is intended for use in conservation, false absences (errors of omission) are more problematic than false presences (errors of commission) especially for the Blanding's turtle, a species at risk. We therefore recommend using a model that is prone to errors of commission (model b) where the model predicts suitable habitat even though the species cannot be detected. While the extent of suitable habitat will always be larger than a species' realized distribution and its overestimation may be preferred, the model should have reasonably good performance so that money and resources are not wasted (Fielding, 1999; Zaniewski et al., 2002).

Our models scored the suitability of an island for Blanding's turtles from 0 to 1, based on the similarity of habitat features on the island relative to a reference island (Fig. 5). We interpret an island with a score of zero to indicate that the island has low probability of having any suitable habitat for Blanding's turtles; conversely, an island with a score of one indicates that the island has very high probability of containing suitable habitat for the Blanding's turtle. We cannot, however, assume habitat suitability scores are proportional to prevalence, which would require model calibration. Our intention is to provide managers a means to identify locations of suitable habitat so they can conduct proper field studies to survey for Blanding's turtles on islands that have high scores.

All models were based on radio tracking data that were pooled from both male and female Blanding's turtles. While our overall goal was to determine suitability of islands based on habitat requirements of both sexes, we also ran models separately for males and females to investigate differences between them. Parameter estimates differed by more than 10%, indicating that males and females do utilize different habitats in their home ranges; however, wetland habitat remained a strong positive predictor of suitability for both sexes. For males, vernal pools were also a positive predictor, highlighting the importance of this habitat feature in the Georgian Bay landscape. We therefore emphasize the need to capture variability in habitat use by males and females when creating overall models of habitat suitability for the Blanding's turtle.

Our models revealed the relative importance of wetlands and vernal pools on islands that are deemed suitable for Blanding's turtles; the higher the amount of wetland and vernal pools, the more suitable the site. Given that the Blanding's turtle is a semi-aquatic species, frequent use of wetlands and vernal pools is expected and confirmed in previous studies (e.g. Joyal et al., 2001; Congdon et al., 2011; Millar and Blouin-Demers, 2011 and Markle and Chow-Fraser, 2014). Both Fortin et al. (2012) and Joyal et al. (2001) found that increase in wetland area increased the probability of Blanding's turtle occupancy. Simulations run by Gibbs (1993) found that when small ephemeral wetlands were lost from the landscape, extinction risk for turtles increased, supporting our finding that vernal pools are relatively important. Our models also suggested that amount of forest had a negative impact on overall island suitability score, or was not significant (Table 2). We do not interpret this as evidence that turtles do not require forest habitat, because other studies have found that probability of turtle presence increased with proportion of forest (Fortin et al., 2012; Quesnelle et al., 2013). Instead, Blanding's turtles have been found to use forest as upland travel corridors (Joyal et al., 2001) and for aestivation (Ross and Anderson, 1990; Joyal et al., 2001) in some populations. We do not know the reason for reported differences, but we know that overall, landscapes with wetlands that are further from roads with more natural habitat composition (i.e. unmodified landscape) are important for sustaining species at risk (Litvaitis and Tash, 2008; Millar and Blouin-Demers, 2012). We propose that it is the matrix of natural landscape with wetlands that contribute to the importance of the Georgian Bay archipelago as being primary habitats for Blanding's turtles.

Since our model scores the suitability of an island based on the proportion of habitat types present on the landscape, naturally, some habitats contribute a higher relative proportion in comparison to the other remaining habitats. These type of data are known as compositional data (Aitchison, 1982) and can lead to collinearity among predictor variables when used in model development. The nature of compositional data can be seen in modelling applications when signs of predictor coefficients differ among models with differing variables (Cade, 2015). For example, in a model without forest as a predictor, rock becomes a positive predictor (Table 2, model b). In a similar fashion, in a model without vernal pools, wetland becomes a negative predictor; however, when this happened in model (f), performance was poor (Table 2). Although some degree of collinearity exists in all field datasets, we aimed to limit impacts of collinearity on our model by restricting our predictions to the Parry Sound Ecodistrict which features similar landscape composition (Dormann et al., 2013). Moreover, in model (b) (i.e. our final model), not all predictor variables were retained in the model and, as a result, data were no longer compositional, which reduces collinearity among predictor variables.

Creating habitat suitability models for species at risk can be challenging as data on the target species are often limited. Not only are species-specific data difficult to acquire, but non-contiguous distribution of species-at-risk can affect the accuracy of habitat suitability models and lead to inflated errors of commission. For instance, even though the target species cannot be detected, suitable habitat may nevertheless exist on islands, as is seen in our final model (model b). In the case of the Georgian Bay archipelago, some of the islands with suitable habitat may be located too far to be colonized by the Blanding's turtle. Moreover, different water level regimes could lead to the formation of land bridges that allow dispersal to new islands or create isolated populations. Since our habitat use models were developed during the summers of 2011 and 2012 (Canadian Hydrographic Service, 2012), all of our habitats have been mapped and suitability predicted based a relatively long period of low water levels. Given that the structure of vegetation communities in coastal wetlands are significantly affected by inter-annual variation of water-levels (Midwood and Chow-Fraser, 2012), our model may be used in a comparison to investigate how changes in wetland habitats affect habitat use by Blanding's turtles under different water-level regimes. Additionally, although an island may be determined to have suitable habitat, other variables may preclude Blanding's turtle's presence such as predator abundance and quality of nesting, feeding and hibernation sites.

It is common to delineate boundaries around habitat features before assigning habitat suitability scores to them (Store and Kangas, 2001), even though these delineated boundaries are artificial and may not necessarily be recognized by wildlife. For instance, Blanding's turtles may be able to make use of several islands within a certain distance of each other on a seasonal basis. Thus, an island without any vernal pools, but that has suitable permanent wetlands, may still be used by Blanding's turtles if it is located within swimming distance of an island with vernal pools. To our knowledge, use of multiple islands has not been reported in Georgian Bay, although there is no reason to believe that multiple island use may not occur. Without data to determine the extent at which Blanding's turtles can swim to access habitats across multiple islands, we choose to evaluate each island separately.

We used high-resolution (5 m per pixel) satellite imagery to classify all habitat types within our study area. Acquisition of satellite imagery occurred during mid-summer (July and August) meaning that we were not able to use these images to map vernal pools. Instead, we used orthophotos acquired during spring, when pools are usually fully inundated and canopy cover is minimal. But, even with the combination of spring imagery and some ground truthing, it is likely that presence of vernal pools had been underestimated. We had neither time nor resources to conduct all the ground surveys to map the full extent of all vernal pools present on the landscape throughout the year, and this should be acknowledged as a limitation. Although undermapping of vernal pools may have reduced the overall suitability score of some islands, we surmise that the error would have been small given the small proportion of vernal pools compared to wetlands, forests and rocks. Since the magnitude of change for a suitability score is dependent on the proportion of all habitat types on the island, addition or subtraction of a few vernal pools would not have changed the overall suitability of the island. We would need more detailed data on movement patterns before we can tease out how Blanding's turtles respond to variation in size, orientation and distribution of vernal pools throughout the landscape.

In Georgian Bay, the only way to protect wetlands and vernal pools is to get them designated as provincially significant under the Ontario Wetland Evaluation System (OWES; Ontario Ministry of Natural Resources and Forestry, 2013b). Typically, wetlands must be larger than 2 ha in order to be eligible for evaluation, but wetlands $<$ 2 ha or those within 750 m of each other may be evaluated if their ecological importance is determined (e.g. presence of species at risk). Midwood et al. (2012) found that 89% of the 3771 coastal wetlands inventoried in Georgian Bay are $<$ 2 ha in size, with an average wetland size of 1.4 ha, but despite their small size supported many important fish species (Midwood and Chow-Fraser, 2014). This inventory suggests that many of the relatively pristine wetlands of Georgian Bay are receiving no formal protection. To receive protection, these wetlands must first be evaluated, and an evaluation is unlikely to be triggered unless nearby development is pending. Given that both wetlands and vernal pools are significant predictors of site suitability in our model results, loss or degradation of either land-cover types could have negative impacts on Blanding's turtles. The importance of vernal pools for Blanding's turtles (Joyal et al., 2001; Markle and Chow-Fraser, 2014) and other species (e.g. amphibians) has been recognized in the literature, but these ephemeral wetlands have yet to receive any formal protection as an independent category. Currently, the only way to protect vernal pools is to have each classified, on a case-by-case basis, as part of a wetland complex through OWES or the Blanding's turtle habitat regulation (Ontario Ministry of Natural Resources and Forestry, 2013a,b).

Ensuring valuable habitats are protected is essential for long-term conservation efforts, especially because human development has increased throughout the archipelago in recent years (Bywater, 2013). For areas experiencing higher levels of development, such as in Severn Sound and Honey Harbour, availability of habitat suitability maps at the scale of each island can help managers design more detailed and effective management plans.

## 5. Conclusion

We mapped suitable Blanding's turtle habitat on islands in the Georgian Bay archipelago based on landscape composition of wetlands, vernal pools, rock, and open water. The most accurate model used data derived from a circular buffer centred on turtles' locations at the larger of the two scales (58 m vs. 24 m). Habitat models that used data derived from the grid approach or using a 24-m scale resulted in high errors of omission, and predicted that between 18% and 55% of evaluated islands provided suitable habitat. By comparison, our most accurate model indicated that 64% of evaluated islands (89% total area) have suitable habitats for Blanding's turtles. The importance of wetlands and vernal pools in determining habitat suitability for Blanding's turtles is reflected in the literature, highlighting their high ecological value within the Georgian Bay archipelago. We produced maps using an interdisciplinary approach combining field data, external validation sites, and a spatial representation of statistical models to identify suitable habitats for Blanding's turtles in the Georgian Bay archipelago. Due to the sensitive nature of data regarding species at risk, our maps do not include names of specific island sites but we intend to freely provide our maps to management agencies, municipalities and interested conservation groups.

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