Monitoring the Northern Population of Copperbelly Water Snake (*Nerodia erythrogaster neglecta*) Using Occupancy Estimation and Modeling to Inform Conservation

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EXECUTIVE SUMMARY

The northern population segment of the Copperbelly Water Snake (*Nerodia erythrogaster neglecta*) is listed as a federally threatened species under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service [USFWS] 2008). This species is known from a small number of locations in south-central Michigan, northwestern Ohio, and northeastern Indiana, and is listed as state endangered in these states (USFWS 2008). Conservation and recovery efforts for this species require estimating and monitoring population size, status, and trends. A statistically robust and efficient long-term monitoring program is needed to facilitate efforts to conserve the Copperbelly Water Snake, but developing such a program for a species that occurs in low densities and when resources are limited can be challenging. Estimating population size also is difficult when detection of a species is imperfect. In recent years, statistical tools, such as occupancy modeling, have been developed to estimate population parameters (e.g., occupancy, abundance) using repeated survey data that incorporate detection probabilities and do not require the capture or identification of individual animals. Occupancy modeling may be a useful approach for long-term monitoring efforts because it allows the estimation of population parameters that could be tracked over time, without the need for more intensive studies, and adjusts estimates for detection probabilities less than one. In 2011, a Copperbelly Water Snake monitoring program was developed and initiated using occupancy estimation and modeling. Surveys were conducted in 2011 to initiate monitoring and collect information to further evaluate the utility of this approach and refine the monitoring program and protocol.

Surveys for the Copperbelly Water Snake were conducted between 30 April and 17 June in 2011 at 19 wetland complexes in the Upper St. Joseph River Watershed in south-central Michigan, northwestern Ohio, and northeastern Indiana. Observers documented presence/absence and number of copperbellies observed during 1-3 visits to 139 wetlands. We used single-season occupancy models developed by MacKenzie et al. (2002), Royle and Nichols (2003), and Royle (2004) to estimate occupancy, probability of detection, and animal density and total abundance. We also utilized the multiple-season model developed by MacKenzie et al. (2003) to estimate occupancy, detection probability, colonization probability, and extinction probability. Population parameters estimated from the 2011 survey data were compared with estimates from the 2005 and 2006 datasets to evaluate and refine the copperbelly monitoring protocol.

Surveys in 2011 documented a total of 32 Copperbelly Water Snake detections in 7 of the 19 wetland complexes surveyed and 15 of the 139 wetlands surveyed. The occupancy models using the 2011 data estimated low levels of Copperbelly Water Snake site occupancy and low detection probabilities. The single-season models generated site occupancy estimates that ranged from 0.19 to 0.38, and detection probabilities that ranged from 0.20 to 0.32. The multiple-season model generated an occupancy estimate of 0.30, and a detection probability of 0.44. Occupancy estimates in 2011 were similar to estimates generated using the 2005 and 2006 data, but detection probability estimates were lower than those generated using the 2005 and 2006 data. Population parameter estimates and their application and monitoring design recommendations from the 2005-2006 analyses and the 2011 analysis were examined and discussed. Additional monitoring recommendations were provided.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

INTRODUCTION

The U.S. Fish and Wildlife Service (USFWS) recognizes two distinct population segments (northern and southern) of the Copperbelly Water Snake (*Nerodia erythrogaster neglecta*), and has listed the northern population segment as a federally threatened species under the U.S. Endangered Species Act of 1973 (USFWS 2008). This population is known from a small number of locations in south-central Michigan, northwestern Ohio, and northeastern Indiana (USFWS 2008). The Copperbelly Water Snake also is listed as state endangered in Michigan, Ohio, and Indiana. This species uses a variety of wetlands, generally preferring shallow wetlands including shrub swamps, emergent marsh, vernal pools, forested swamps, and the margins of open water areas, which are usually characterized by open canopies, shallow water, and short dense shrub and/or emergent vegetation (Herbert 2003, Kingsbury et al. 2003, Lee et al. 2005 and 2007, USFWS 2008). Copperbelly Water Snakes also use uplands, particularly forested uplands, for foraging, aestivating, hibernating, and traveling among wetlands, and they are known to use uplands more often than Northern Water Snakes (*Nerodia sipedon sipedon*; Kingsbury et al. 2003, Roe et al. 2004, USFWS 2008). Copperbelly Water Snakes require large habitat complexes comprised of multiple, suitable wetlands within a matrix comprised primarily of upland forests and some open upland habitats, with snakes frequently using and moving between multiple wetlands and between wetland and upland habitats (Kingsbury et al. 2003, Roe et al. 2003, 2004). Habitat loss, degradation, and fragmentation are viewed as the primary threats to the Copperbelly Water Snake (USFWS 1997, 2008).

To inform planning and implementation of conservation and recovery efforts for the northern population of the Copperbelly Water Snake, the U. S. Fish and Wildlife Service and its partners need information on the status and trends of this population. This information also can be used to evaluate the success of conservation efforts and assess progress towards recovery and delisting of the species or population. The Copperbelly Water Snake Recovery Plan (USFWS 2008) provides a set of criteria to assess delisting or reclassification of the population, which requires estimation of population size. However, estimation of population size is difficult when detection of the species is imperfect. Additionally, estimating population size or abundance of rare species can be particularly challenging, or practically impossible in some cases (MacKenzie et al. 2004a, 2005, 2006). A statistically robust and efficient long-term monitoring program is needed to inform and help guide conservation and recovery efforts for the northern population of the Copperbelly Water Snake, but developing such a program for a species that occurs in low densities and when resources are limited can be challenging. A variety of methods have been employed by the USFWS and its partners (e.g., Michigan Natural Features Inventory [MNFI], Indiana-Purdue University at Fort Wayne [IPFW]), including repeated surveys of wetlands, distance sampling, radio telemetry, and mark-recapture studies. Funding and personnel constraints and low population levels make some of these methods unfeasible for evaluating the species' population status over large spatial and temporal scales.

In recent years, statistical tools, such as occupancy modeling, have been developed to estimate population parameters (e.g., occupancy, abundance) using repeated survey data that incorporate detection probabilities and do not require the capture or identification of individual animals (e.g., MacKenzie et al. 2002, 2003, Royle and Nichols 2003, Royle 2004). Occupancy modeling may be a useful approach to incorporate into a long-term monitoring program because it allows the estimation of population parameters that could be tracked over time, without the need for more intensive studies, and adjusts estimates for detection probabilities less than one (i.e., some individuals are present but not detected). Also, for some rare species, estimating occupancy may be more feasible or practical than estimating population size or abundance (MacKenzie et al, 2006). To investigate the utility of this approach for monitoring Copperbelly Water Snakes, the U. S. Fish and Wildlife Service contracted with the MNFI to reanalyze existing copperbelly survey data using occupancy modeling. Copperbelly presence-absence (or detection/non-detection) data and count data from surveys conducted at known extant sites in Michigan and Ohio in 2005 and/or 2006 by the MNFI and IPFW were compiled and analyzed using occupancy modeling. The data analysis was able to generate estimates of occupancy, abundance, and detection probability. The occupancy and detection probability estimates provided initial data for determining the number of survey visits and number of study sites needed to achieve different levels of precision based on guidance provided by MacKenzie and Royle (2005). Recommendations were provided for designing a Copperbelly Water Snake monitoring program based on the data analysis and results, relevant literature, and evaluation of the previous monitoring approach/protocol and population estimate. A detailed summary of the data analysis using occupancy modeling, associated results, and monitoring design recommendations is provided in Monfils and Lee (2011). A brief summary of the occupancy modeling results and monitoring recommendations is provided in Appendix 1.

Based on the initial occupancy estimation and modeling results and recommendations, the U.S. Fish and Wildlife Service and its partners at the Michigan Natural Features Inventory (MNFI) and Indiana-Purdue University at Ft. Wayne (IPFW) recently developed a monitoring approach and protocol and initiated a long-term monitoring program for the northern population of the Copperbelly Water Snake. The monitoring program currently has three objectives. The main objective of the monitoring program at this time is to detect trends or changes in the northern copperbelly population. This will be accomplished primarily by estimating and monitoring occupancy in terms of the proportion of wetland complexes and individual wetlands occupied by copperbellies in the study area. Additional objectives of the monitoring program include assessing population status and trends by estimating and monitoring population size or abundance and assessing the effectiveness of habitat restoration efforts. The current monitoring program strives to address these additional objectives to some degree, but additional, targeted monitoring efforts will likely be needed to fully address these objectives.

This report summarizes the results of the copperbelly surveys conducted in 2011 to initiate monitoring of the northern copperbelly population using occupancy estimation and modeling and the new monitoring protocol that was recently developed. The field surveys and associated results provided additional data and insights to help clarify and refine the copperbelly monitoring protocol and program. A detailed overview and explanation of the copperbelly monitoring program and protocol as well as considerations or recommendations for refining the monitoring program are provided in this report. The copperbelly monitoring protocol should be viewed as a work in progress and may need to be refined in the first couple of years based on additional data and insights from initial surveys.

METHODS

Study Area

The study area for the copperbelly monitoring program is located in the northern half of the Upper St. Joseph River Watershed in Hillsdale County in Michigan, Steuben County in Ohio, and Williams County in Indiana. This area includes the recent distribution and a portion of the historical distribution of the northern copperbelly population. The study area contains a variety of wetland types and sizes, ranging from small, temporary or semi-permanent wetlands to larger, permanent wetlands and waterbodies (Lee et al. 2007). Wetland natural community types commonly found in the study area consist of inundated shrub swamp, southern wet meadow, emergent marsh, southern floodplain forest, and southern swamp (Kost et al. 2006). The St. Joseph of the Maumee River flows through the study area. The upland landscape consists of a matrix of forest and shrub-scrub habitats, old fields, active agricultural fields and pastures, numerous roads, and rural residences and farms (Lee et al. 2007).

Sampling Design

The sample frame, from which sample units or sites were selected, consists of wetland complexes within 400 meters of recent (i.e., copperbellies observed post-2000) or historic (copperbellies observed pre-2000) copperbelly occurrences and wetland complexes within a 5-km (3 mi) buffer of those complexes in the study area (Kahler pers. comm.). The wetland complexes were identified and delineated in the Copperbelly Water Snake Habitat Suitability Index (HSI) model developed by the USFWS. A wetland complex consists of a cluster of National Wetland Inventory (NWI) polygons aggregated within a 200-m buffer and not bisected or separated by paved roads (Kahler pers. comm.). Each wetland complex in the habitat suitability index (HSI) model has a HSI score based on the average HSI score for individual wetland polygons within the complex. Habitat suitability index scores range from 0 to 1, with scores increasing with habitat suitability. Currently, only NWI polygons and wetland complexes with HSI scores $\geq$ 0.60 were included in the sample frame. This included all recent copperbelly occurrences and some historic occurrences. A wetland complex associated with an historic copperbelly occurrence (i.e., Douglas Woods) that was of particular interest was added to the sample frame.

Wetland complexes were identified as the sample unit of interest or sample site. Wetland complexes within the sample frame were stratified and selected for surveys based on their copperbelly occupancy status and HSI score. Wetland complexes with NWI polygons that contained copperbelly sightings since or post-2000 were classified as “Recent” wetland complexes. Sixteen wetland complexes were originally classified as “Recent” wetland complexes. The wetland complex immediately south of where a dead copperbelly had been found on the road at a new site in 2010 was added to the list of “Recent” wetland complexes, resulting in 17 total “Recent” wetland complexes. Wetland complexes with NWI polygons that contained copperbelly sightings prior to 2000 were classified as “Historic” wetland complexes. The remaining wetland complexes in which copperbellies have not observed were classified as “Unknown” wetland complexes. Wetland complexes also were classified as “High HSI” or “Low HSI” complexes based on their HSI scores. “High HSI” wetland complexes had HSI scores $\geq$

0.75, and “Low HSI” wetland had HSI scores between 0.60 and 0.75. Wetland complexes classified as “Historic” or “Unknown” were classified as “High HSI” or “Low HSI” based on their HSI scores. This resulted in 55 historic and unknown wetland complexes classified as “High HSI,” and 113 historic and unknown wetland complexes classified as “Low HSI.” This resulted in a total of about 185 wetland complexes that were included as potential sample sites (Kahler pers. comm.).

All wetland complexes classified as “Recent” (regardless of HSI score) were surveyed in 2011. These complexes will be surveyed every year according to the monitoring protocol. All “High HSI” and “Low HSI” historic and unknown wetland complexes were randomly drawn sequentially for surveys using a generalized random-tessellation stratified (GRTS) sampling design. A GRTS sampling design is basically a modified version of or compromise between simple random sampling and systematic sampling that provides a spatially-balanced sampling design. Stevens and Olsen (2004) and Johnson et al (2009) provide detailed information about a GRTS sampling design. Sites were selected for sampling the R software package. The GRTS sampling design produced an ordered list of “High HSI” and “Low HSI” wetland complexes that will be surveyed in order of appearance or selection depending on available resources. All wetland complexes classified as “High HSI” (that we can access) will be surveyed prior to wetland complexes classified as “Low HSI” complexes. If a copperbelly is detected in a “High HSI” or “Low HSI” historic or unknown wetland complex, the complex will be added to the list of “Recent” wetland complexes, and thus will be surveyed annually in all subsequent years.

Wetland complexes selected for sampling contained multiple wetlands, ranging from 1 to over 62 individual NWI polygons. Mean number of wetland polygons ranged from about 8-12 wetland polygons per complex, and median number of polygons ranged from about 6-7 wetlands per complex (Kahler pers. comm.). Within wetland complexes, observers selected and surveyed for copperbellies at multiple individual wetlands. Wetlands known or likely to harbor copperbellies were targeted for surveys. Wetlands selected for surveys typically consisted of palustrine shrub-scrub (PSS), particularly those dominated by buttonbush; palustrine forest (PFO), particularly small palustrine forest wetlands or vernal pools < 3 ha (7 ac); palustrine emergent (PEM); and palustrine unconsolidated bottom (PUB) wetlands.

Copperbelly Water Snake Surveys

Observers surveyed a total of 19 wetland complexes and 139 individual wetlands within those complexes between 30 April and 17 June in 2011. Of the 19 wetland complexes surveyed, 14 of the complexes were classified as “Recent” wetland complexes, and 5 were classified as “High HSI” wetland complexes, which consisted of 1 wetland complex classified as “Historic” and 4 complexes classified as “Unknown.” Surveys were conducted in a couple of wetland complexes near the site where a copperbelly was first documented in 2010. Due to time, weather and other logistical constraints, three of the recent wetland complexes were not surveyed. In 2011, the number of wetlands surveyed within wetland complexes ranged from 4 to 16, and the average number of wetlands surveyed per complex was 7. Sites in Michigan were primarily surveyed by Yu Man Lee with the MNFI, and sites in Ohio and Indiana were surveyed primarily by Dr. Bruce Kingsbury and Adam Bauer with IPFW.

The monitoring protocol stipulates three survey visits to each wetland complex and individual wetlands selected for surveys, with each of the three survey visits occurring in specified time periods to control for the effect of survey timing. The three time periods initially set for the three survey visits consisted of the following: (1) April 15 to May 5; (2) May 6 to May 25; and (3) May 26 to June 15. Due to weather and access issues and other logistical constraints, the survey time periods were shifted slightly (see Data Analysis section below). Three survey visits were conducted at most of the wetland complexes (i.e., all but three) in 2011. However, most individual wetlands within complexes were surveyed two to three times, with a small number of wetlands (i.e., 13 wetlands in 9 different complexes) surveyed only once during the season (**0** = 2.4 surveys/site or wetland, n = 139).

Visual encounter surveys for Copperbelly Water Snakes were conducted at individual wetlands by walking slowly along the entire length of the shoreline of the wetland, and in some cases in shallow water along the wetland edge or in the wetland interior, and surveying the vegetation and open water from one or more fixed locations with binoculars. In a few cases when it was not possible to walk or wade around a portion of a wetland, surveys were only conducted with binoculars from points offering the best view. One observer generally conducted the surveys at a given wetland complex. On several occasions, two observers conducted surveys within a wetland complex. In these instances, observers would separate and survey half of each wetland independently. Observers only conducted surveys during appropriate weather conditions when snakes were expected to be most visible. A detailed description of the survey methods was provided by Lee et al. (2007).

During each survey visit, observers recorded survey locations (i.e,, wetland complex/wetland group ID and individual wetlands surveyed/Wet_ID), survey visit, survey date and times, water levels (full, moderate, dry), general wetland or shoreline description, the number of copperbellies observed, and number of other snakes and herps observed for each wetland surveyed (Appendix 2). Surveyors also recorded weather conditions including air temperature, sun/cloud cover, general wind speed/conditions, and precipitation during each survey visit to a wetland complex. Surveyors recorded the locations of wetlands surveyed, survey routes, and copperbelly observations using GPS. Copperbelly observations and other relevant information from surveys conducted in Michigan in 2011 will be entered into the Michigan Natural Heritage Database to update copperbelly element occurrence records in the database. Copperbelly observations documented in Ohio will be provided to the Ohio Department of Natural Resources.

Data Analysis

We shifted the survey time periods slightly and arranged the 2011 survey data into the following three periods to control for the effect of survey timing, evaluate models in which detection probability varied by period, and match the time periods used in the analysis of the 2005 and 2006 data to facilitate multi-season comparisons: (1) April 15 to May 10; (2) May 11 to May 31; and (3) June 1 to June 20. These survey periods were selected to coincide with typical changes in weather and vegetation conditions that might affect snake activity and visibility. At two sites/wetland complexes, this shift in survey periods resulted in two surveys occurring within one of the post-hoc survey periods. In those situations, we considered Copperbelly Water Snake present for the survey period if it was observed during at least one survey and used the maximum number of snakes observed among the surveys when estimating abundance. This resulted in reducing the number of survey visits to those wetland complexes and wetlands from three to two survey visits. At two other wetland complexes, this shift in survey periods resulted in shifting the survey data into one of the other post-hoc survey periods and keeping the same number of survey visits.

In several wetland complexes, wetlands that were mapped as individual or separate NWI wetland polygons were actually part of one contiguous wetland or waterbody in the field. These wetlands were surveyed as one wetland in the field, and were treated as one wetland in the analysis at this time. In a couple of instances, wetlands were surveyed and treated as separate wetlands in the field but were mapped as one or a single NWI wetland polygon or may be connected hydrologically and likely represent or function as one contiguous wetland. Survey data from these wetlands were merged and treated as one wetland in the analysis. Five wetlands were surveyed only once or twice in 2011 or in 2005 and 2006, were not surveyed during subsequent survey visits to the site, and will not be surveyed in future years due to unsuitable habitat, locational uncertainty, or sufficient survey effort in the complex. These wetlands were removed from the analysis. These adjustments resulted in a total of 134 sites surveyed in 2011 that were included in the analysis.

We used models available in PRESENCE 3.1 (http://www.mbr-pwrc.usgs.gov/software/presence.shtml) to estimate population parameters for the northern population of Copperbelly Water Snake. Although wetland complexes are the sample units of interest, the occupancy modeling was conducted using survey data from individual wetlands to increase sample size. This was discussed with and recommended by Darryl MacKenzie (pers. comm.), an expert in occupancy modeling who helped develop this tool. Under this scenario, we assume the movement of snakes between wetlands within complexes occurred randomly, and the occupancy estimator should be viewed as the proportion of sites (i.e., wetlands) used by the target species (MacKenzie et al. 2006). Detection probability is the probability the species is present at the time of the survey and is detected at the occupied sites. Covariates that might influence occupancy and detection probability were not available at the time of analysis, so we only used simple models lacking covariates. We used the same models that were used by Monfils and Lee (2011) to analyze the 2005 and 2006 data to analyze the 2011 data to allow comparisons between the results. A discussion of the assumptions of the models used in our analyses is provided in detail in Monfils and Lee (2011).

Single-season Models

We estimated site occupancy (i.e., Ψ, proportion of sites occupied) and probability of detection (p) for 2011 using the approach described by MacKenzie et al. (2002). For each season, we ran two predefined models in PRESENCE: (1) detection probability constant across surveys, and (2) variable detection probability among surveys. We assessed which of the two models was “best” supported by the data in each year using the Akaike Information Criterion (AIC).

Two recently developed modeling methods (Royle and Nichols 2003, Royle 2004) built upon the single-season model developed by MacKenzie et al. (2002) to allow estimation of animal density and total abundance, in addition to occupancy and detectability. Royle and Nichols (2003) provided a method of abundance estimation using detection-nondetection data, whereas Royle

(2004) developed a model to estimate abundance with count data from repeat surveys. We ran both models using the 2011 data to provide coarse Copperbelly Water Snake abundance estimates. These estimates can serve as additional population indicators that can be examined and tracked over time to detect population trends.

Single-season model results from 2011 were compared with model results generated from the 2005 and 2006 data to evaluate initial population parameter estimates. Results from 2011 were primarily compared with results from 2005 because the number and locations of sites surveyed in 2011 were similar to those surveyed in 2005. The 2006 dataset was much smaller and only included survey data from three wetland complexes in Michigan.

Multiple-season Models

We analyzed data from 2005, 2006, and 2011 using the model developed by MacKenzie et al. (2003). This analysis only included data from three "recent" wetland complexes in Michigan because we have survey data from many of the same wetlands in these complexes from all three years. The model developed by MacKenzie et al. (2003) allows estimation of occupancy, detection probability, colonization probability (i.e., probability that an unoccupied site in season one will become occupied in season two), and extinction probability (i.e., probability that an occupied site in season one will become unoccupied in season two). We compared the following four simple multi-season models: (1) occupancy and detection probability constant across seasons and surveys; (2) occupancy varying by season and detection probability constant across seasons and surveys; (3) occupancy and detection probability varying by season; and (4) occupancy varying by season and detection probability varying among all surveys. We assessed which of the models was "best" supported by the data using AIC.

RESULTS

Copperbelly Water Snake Surveys

Surveys in 2011 documented a total of 32 Copperbelly Water Snake observations or detections. Copperbellies were detected in 7 of the 19 wetland complexes and 15 of the 139 wetlands surveyed in 2011. The seven wetland complexes in which copperbellies were documented in 2011 are wetland complexes in which copperbellies have been recently documented (post-2000). A dead copperbelly was found along the edge of a small pond or palustrine unconsolidated bottom wetland in one of the "recent" wetland complexes in Michigan. The cause of death is unknown, but the snake may have been run over by the tire of a mower since it was found along the edge of the wetland adjacent to a mowed grassy area. Copperbellies were not detected in the two wetland complexes surveyed near the new copperbelly site documented in Michigan in 2010 although suitable wetland habitats for the copperbelly were found in these complexes.

In addition to Copperbelly Water Snakes, a number of other amphibian and reptiles were observed (seen or heard) during surveys in 2011. These include Northern Water Snakes (*Nerodia sipedon sipedon*), Northern Ribbon Snakes (*Thamnophis sauritus septentrionalis*), Painted Turtles (*Chrysemys picta*), Eastern Spiny Softshell (*Apalone spinifera spinifera*), Eastern Snapping Turtle (*Chelydra serpentina serpentina*), Western Chorus Frogs (*Pseudacris* *triseriata*), Green Frogs (*Lithobates [Rana] clamitans*), American Bullfrogs (Lithobates *[Rana] catesbeianus*), Wood Frogs (*Lithobates [Rana] sylvaticus*), American Toads (*Anaxyrus [Bufo] americanus*), and Northern Cricket Frogs (*Acris crepitans*) or Blanchard's Cricket Frogs (*Acris crepitans blanchardi*). The Northern or Blanchard's Cricket Frog is listed as a state threatened species in Michigan, and was heard at four different wetlands in two wetland complexes, including a new area from which the species has not been documented.

Single-season Models

Using several single-season occupancy models, we estimated low levels of Copperbelly Water Snake site occupancy and low detection probabilities based on the 2011 data. Two models, one with constant occupancy and detection probabilities and the second containing abundance-induced heterogeneity in detection probability (Royle and Nichols 2003), were similarly supported by the 2011 data (Table 1). Burnham and Anderson (2002) stated that models with AIC differences less than two have substantial empirical support. In 2011, naïve occupancy was 0.11, whereas both of the best-approximating models, the constant occupancy and detectability model and the abundance-induced heterogeneity model, estimated occupancy at 0.19 (SE=0.06) and 0.20 (SE=0.07), respectively (Table 2). Detection probability was similar for the two best-supported 2011 models, with an estimate of 0.32 (SE=0.10) for the constant occupancy and detectability model and 0.29 (SE=0.11) for the abundance-induced heterogeneity model (Table 2). The repeated-count model (Royle 2004) produced a greater occupancy estimate (0.38, SE=0.12) and lower probability of detection (0.20, SE=0.08) than the other 2011 models.

Similar to the low estimates of occupancy, we obtained low abundance estimates using the Royle and Nichols (2003) and Royle (2004) models (Table 2). We estimated average Copperbelly Water Snake abundance at 0.22 (SE=0.09) snakes per site using the abundance-induced heterogeneity model and 0.48 (SE=0.19) snakes per site with the repeated-count model. Total abundance for the sites surveyed was estimated at 31.8 (SE=12.5) by the abundance-induced heterogeneity model and 69.4 (SE=27.0) by the repeated-count model.

The 2011 single-season occupancy model results were fairly similar to the 2005 single-season model results. The constant occupancy and detection probability model and the abundance-induced heterogeneity model ranked the highest and were best-supported by the data in 2005 and 2011. Both these models generated similar observed and estimated occupancy in 2005 and 2011. In 2005, naïve occupancy was 0.14 and estimated occupancy was 0.17 (SE=0.04) for both models (Table 3). In 2011, naïve occupancy was 0.11 and estimated occupancy were 0.19 (SE=0.06) and 0.20 (SE=0.07) for the two models in 2011 (Table 3). The repeated-count model also generated similar occupancy estimates in 2005 and 2011, with 0.31 (SE=0.07) in 2005 and 0.38 (SE=0.12) in 2011 (Table 3). However, detection probability estimates were lower in 2011 than in 2005, ranging from 0.20 (SE=0.08) to 0.32 (SE=0.10) in 2011 compared to 0.40 (SE=0.09) to 0.58 (SE=0.10) in 2005. The single-season occupancy models estimated lower occupancy and detection probability in 2011 compared to 2006 (Table 3).

Average and total copperbelly abundance estimates were slightly higher with the 2011 data than the 2005 data. Average abundance estimates were 0.22 (SE=0.09) snakes per site in 2011 and 0.19 (SE=0.05) in 2005 using the abundance-induced heterogeneity model, and 0.48 (SE=0.19) snakes per site in 2011 and 0.38 (SE=0.10) in 2005 with the repeated-count model. Total abundance estimates were 31.8 (SE=12.5) in 2011 compared to 19.7 (SE=5.6) in 2005 for the abundance-induced heterogeneity model, and 69.5 (SE=27.0) in 2011 compared to 39.4 (SE=10.1) in 2005 for the repeated-count model (Table 3). But the standard errors and confidence intervals for abundance estimates in 2011 also were higher than the 2005 estimates.

Table 1. Summary of single-season models used to estimate occupancy (Ψ) and detection probability (*p*) for Copperbelly Water Snake detection-nondetection data from 2011 at sites in Michigan, Ohio, and Indiana.

Model	ΔAIC	AIC Weight	No. Parameters
2011 (n=145)[1]			
Ψ (.), *p* (.)	0.00	0.4726	2
Ψ (.), *p* (abundance-induced heterogeneity)[2]	0.16	0.4362	2
Ψ (.), *p* (survey-specific)	3.29	0.0912	4

[1] Sample size includes 134 wetlands surveyed in 2011 and 11 additional wetlands that were surveyed in 2005 and/or 2006 but were not surveyed in 2011. These were included in the analysis as missing data.

[2] Royle and Nichols (2003) estimator.

Table 2. Observed and model-estimated Copperbelly Water Snake population parameters, standard errors (SE), and lower and upper 95% confidence limits (LCL and UCL) for single-season models fit to 2011 survey data from Michigan, Ohio, and Indiana.

	Occupancy					Detection Probability				Total Abundance			
Model	Naïve	Est. Ψ	SE	LCL	UCL	p	SE	LCL	UCL	N	SE	LCL	UCL
2011 (n=145)[1]													
Single-season Occupancy[2]	0.11	0.19	0.06	0.10	0.35	0.32	0.10	0.16	0.54	NA[3]	NA	NA	NA
Abundance-induced Heterogeneity[4]	0.11	0.20	0.07	0.06	0.33	0.29	0.11	0.08	0.50	31.8	12.5	7.2	56.4
N-Mixture Repeated Count[5]	0.11	0.38	0.12	0.15	0.61	0.20	0.08	0.05	0.35	69.5	27.0	16.6	122.4

[1] Sample size includes 134 wetlands surveyed in 2011 and 11 additional wetlands that were surveyed in 2005 and/or 2006 but were not surveyed in 2011. These were included in the analysis as missing data.
[2] MacKenzie et al. (2002) model.
[3] Parameter is not estimated by the model.
[4] Royle and Nichols (2003) estimator.
[5] Royle (2004) model.

Table 3. Observed and model-estimated Copperbelly Water Snake population parameters, standard errors (SE), and lower and upper 95% confidence limits (LCL and UCL) for single-season models fit to 2005, 2006, and 2011 survey data from Michigan, Ohio, and/or Indiana.

	Occupancy					Detection Probability				Total Abundance			
Model	Naïve	Est. Ψ	SE	LCL	UCL	p	SE	LCL	UCL	N	SE	LCL	UCL
2005 (n=105)													
Single-season Occupancy[1]	0.14	0.17	0.04	0.08	0.26	0.58	0.10	0.37	0.78	NA[2]	NA	NA	NA
Abundance-induced Heterogeneity[3]	0.14	0.17	0.04	0.08	0.26	0.55	0.11	0.33	0.77	19.7	5.6	8.6	30.9
N-Mixture Repeated Count[4]	0.14	0.31	0.07	0.18	0.44	0.40	0.09	0.23	0.58	39.4	10.1	19.7	59.2
2006 (n=31) [5]													
Single-season Occupancy[1]	0.19	0.31	0.15	0.00	0.62	0.46	0.21	0.03	0.90	NA[2]	NA	NA	NA
2011 (n=145)[6]													
Single-season Occupancy[1]	0.11	0.19	0.06	0.10	0.35	0.32	0.10	0.16	0.54	NA[2]	NA	NA	NA
Abundance-induced Heterogeneity[3]	0.11	0.20	0.07	0.06	0.33	0.29	0.11	0.08	0.50	31.8	12.5	7.2	56.4
N-Mixture Repeated Count[4]	0.11	0.38	0.12	0.15	0.61	0.20	0.08	0.05	0.35	69.5	27.0	16.6	122.4

[1] MacKenzie et al. (2002) model.

[2] Parameter is not estimated by the model.

[3] Royle and Nichols (2003) estimator.

[4] Royle (2004) model.

[5] Michigan sites only.

[6] Sample size includes 134 wetlands surveyed in 2011 and 11 additional wetlands that were surveyed in 2005 and/or 2006 but were not surveyed in 2011. These were included in analysis as missing data.

Multiple-season Models

As with the multi-season model with just the 2005 and 2006 data, we found the model with constant occupancy and detection probability among years and surveys to be the best-approximating model of those examined (Table 4). However, unlike the 2005-2006 multi-season model results, the second best-approximating model (occupancy varying by season and constant detection probability) had an AIC difference greater than two, indicating it was not supported by the data (Burnham and Anderson 2002). Of the sites (i.e., wetlands) available for multi-year analysis, Copperbelly Water Snake was observed during at least one survey in 0.15 of the sites in 2005, 0.19 of the sites in 2006, and 0.19 of the sites in 2011. The model best supported by the data provided an occupancy estimate of 0.30 (SE=0.08) for all three years (Table 5). The best-approximating model produced a detection probability estimate of 0.44 (SE=0.10), and estimated the probability of colonization at 0.24 (SE=0.10) and extinction probability at 0.57 (SE=0.19).

The multi-season model with data from 2005, 2006, and 2011 generated a slightly higher occupancy estimate (Ψ = 0.30, SE=0.08) for all three years than those generated by the multi-season models with only the 2005 and 2006 data (Ψ=0.22, SE=0.07 and Ψ=0.19, SE=0.08) (Tables 5 and 6). The detection probability estimate for the model with all three years (p=0.44, SE=0.10) was lower than those for the 2005-2006 models (p=0.59, SE=0.13 for both models). The colonization probability for the multi-season model with all three years (γ=0.24, SE=0.10) was slightly higher than those generated by the 2005-2006 model (γ=0.17, SE=0.08, and γ=0.21, SE=0.11). The extinction probability for the model with all three years (ε=0.57, SE=0.19) was slightly lower or comparable to estimates for the 2005-2006 models (ε=0.62, SE=0.21 and ε=0.57, SE=0.26) (Tables 5 and 6).

Table 4. Summary of multi-season models used to estimate Copperbelly Water Snake occupancy (Ψ) and probabilities of detection (p), extinction (ε), and colonization (γ) during 2005-2006 and 2011 at a subset of sites in Michigan.

Model[1]	ΔAIC	AIC Weight	No. Parameters
Ψ (.), γ, ε, p (.)	0.00	0.7826	3
Ψ (season), γ, ε, p (.)	3.61	0.1287	5
Ψ (season), γ, ε, p (season)	4.37	0.0880	7
Ψ (season), γ, ε, p (survey-specific)	14.16	0.0007	13

[1] MacKenzie et al. (2003) multi-season occupancy model.

Table 5. Observed and model-estimated Copperbelly Water Snake occupancy (Ψ) and probabilities of detection (*p*), extinction (ε), and colonization (γ) based on 2005, 2006, and 2011 data from three “recent” wetland complexes in Michigan.

2005-2006, 2011	Occupancy												
		2005				2006				2011			
Model	Obs.[1]	Ψ	SE	LCL	UCL	Ψ	SE	LCL	UCL	Ψ	SE	LCL	UCL
Ψ (.), γ, ε, *p* (.)	0.31	0.30	0.08	0.16	0.49	0.30	0.08	0.16	0.49	0.30	0.08	0.16	0.49

2005-2006, 2011	Detection Probability				Colonization Probability				Extinction Probability			
Model	*p*	SE	LCL	UCL	γ	SE	LCL	UCL	ε	SE	LCL	UCL
Ψ (.), γ, ε, *p* (.)	0.44	0.10	0.25	0.64	0.24	0.10	0.10	0.48	0.57	0.19	0.20	0.94

[1] Observed or naïve occupancy.

Table 6. Observed and model-estimated Copperbelly Water Snake occupancy (Ψ) and probabilities of detection (*p*), extinction (ε), and colonization (γ) based on 2005 and 2006 data from three recent wetland complexes in Michigan.

	Occupancy									Detection Probability				Colonization Probability				Extinction Probability			
2005-2006		2005				2006															
Model	Obs.[1]	Ψ	SE	LCL	UCL	Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	γ	SE	LCL	UCL	ε	SE	LCL	UCL
Ψ (.), γ, ε, *p* (.)	0.23	0.22	0.07	0.07	0.36	0.22	0.07	0.07	0.36	0.59	0.13	0.33	0.81	0.17	0.08	0.07	0.38	0.62	0.21	0.21	1.04
Ψ (season), γ, ε, *p* (.)	0.23	0.19	0.08	0.03	0.35	0.25	0.10	0.05	0.44	0.59	0.13	0.33	0.81	0.21	0.11	-0.01	0.43	0.57	0.26	0.04	1.10

[1] Observed or naïve occupancy.

DISCUSSION

Surveys

Survey results in 2011 were similar to survey results obtained in 2005. Surveys in 2011 documented 32 copperbelly observations or detections in 15 different wetlands. Surveys in 2005 documented 38 copperbelly observations in 15 wetlands. Many of the same wetlands and wetland complexes were surveyed in 2011 and in 2005, and Copperbelly Water Snakes were documented in some of the same wetlands in both years. Copperbelly Water Snakes appear to exhibit site fidelity and tend to use the same wetlands from year to year, and also tend to use some wetlands more frequently than other wetlands (Herbert pers. comm.). This could have contributed to similar numbers and locations of copperbelly observations documented in 2011 and 2005. However, copperbellies also were documented in some different wetlands in 2011 and 2005. The number of copperbelly observations and number of individual wetlands and wetland complexes in which copperbellies were documented in 2011 remain quite low and should continue to be closely monitored.

Population Parameter Estimates

Observed and estimated occupancy in 2011 were fairly consistent with observed and estimated occupancy generated from the 2005 and 2006 data. Occupancy estimates based on the 2005 and 2006 data ranged from 0.17 to 0.31 across the various single-season and multi-season models. Occupancy estimates in 2011 ranged from 0.19 to 0.38. This helps validate our initial occupancy estimates from 2005 and 2006. Because our surveys in 2011 focused mainly on recent wetland complexes and we only surveyed a small number of historic or unknown wetland complexes, we likely surveyed many of the same sites in 2011 that were surveyed in 2005 and/or 2006. Copperbellies also appear to occur and were documented in the same wetland complexes and some of the same wetlands in 2011 as in 2005 and/or 2006. These two factors likely contributed to similar results in 2011 as in 2005 and 2006. Again, copperbelly occupancy appears to remain fairly low.

While occupancy estimates were similar across the three years, detection probability was lower in 2011 than in 2005 and 2006. Detection probability estimates in 2011 ranged from 0.20 to 0.44 across the various occupancy models, while detection probability estimates generated from the 2005 and 2006 data ranged from 0.40 to 0.59 across the various models. The lower detection probability estimates in 2011 may have been due to additional wetland complexes surveyed in 2011 which were historic or unknown copperbelly sites whereas surveys in 2005 and 2006 focused on known or recent copperbelly sites. Survey covariates, such as weather conditions, observer skill, experience and/or familiarity with the survey site, and changes in habitat conditions, also could have impacted detectability in 2011. Including covariates in future occupancy analyses could help identify potential factors that affect detectability, assess their impacts, and inform potential changes to the survey protocol.

Average and total abundance estimates in 2011 were higher than those generated with the 2005 data. One factor that likely contributed to higher total abundance estimates in 2011 is the larger number of sites (i.e., wetlands) that were surveyed in 2011 since the total abundance estimate is derived by multiplying the average abundance estimate by the total number of sample sites. As mentioned earlier though, because of potential issues with some of the assumptions of these models, abundance estimates generated from these models should be viewed as coarse measures or indicators of abundance at this time. The abundance estimates also can be used to help detect and monitor trends in the population. As a side note, total abundance estimates generated by occupancy models with data from 2005 and 2011 were lower than the estimated total adult Copperbelly Water Snake population size (N=94 ± 22) generated using distance sampling and survey data from 34 wetlands in 2006 (Attum et al. 2009).

The occupancy models we have been using generally assume that sample sites are selected using a probabilistic design, which would produce a sample of sites representative of the study area. Given that the sites surveyed in 2011 were still primarily comprised of recent wetland complexes that were selected based on recent observations of Copperbelly Water Snakes, the parameter estimates should not be applied beyond the sites surveyed (i.e., estimates could be biased for the entire population). Because the abundance estimates we produced are based on the estimated mean number of snakes per site, this estimator should not be applied beyond the sites surveyed due to the manner in which sites were selected. However, sample sites of historic or unknown copperbelly occupancy (i.e., high HSI-and low HSI- designated wetland complexes) have been identified and selected for surveys using a probabilistic sample design, and surveys were conducted at a small number of these sites in 2011. Surveying these sites in the future as part of the copperbelly monitoring program will produce a sample of sites that is representative of the study area, and population parameter estimates could then be applied to the entire population.

With the 2005 and 2006 data, inconsistencies in the way the data were collected and small sample sizes for some analyses may have reduced the precision of our parameter estimates. Because the timing of the surveys was not consistent in 2005 and 2006, missing observations were common in the datasets. Although the occupancy models we used are robust to missing observations, precision of the estimates decreases as the number of missing observations increases (MacKenzie et al. 2002, 2003). We tried to address this issue in 2011 by trying to visit each wetland three times, once during each of the specified time periods, but we still ended up with some missing data due to time, weather, and other logistical constraints, and access issues. We also had to adjust some of the survey time periods for some of the data to make the data more consistent for the analysis which reduced the number of survey visits for some sites. For the multi-season model that included data from 2005, 2006 and 2011, several wetlands that were surveyed in 2005 and/or 2006 were not surveyed in 2011, and a couple of new wetlands were added in 2011, which resulted in missing data in the analysis. Missing data in the 2011 dataset (and in the 2005 and 2006 datasets for the multi-season model) may have reduced the precision of some of the parameter estimates, particularly those generated by the multi-season model. As a result, current population parameter estimates at this time should still be viewed as preliminary.

Monitoring Recommendations

Results from the 2005 and 2006 data analyses (Monfils and Lee 2011) and the 2011 monitoring effort demonstrate that occupancy estimation and modeling can be a useful approach for a Copperbelly Water Snake monitoring program. While some issues with the 2005 and 2006 datasets were addressed in the copperbelly monitoring design and protocol, results from the 2011 monitoring surveys indicate the following issues still need some attention and should try to be addressed in future discussions and monitoring efforts. Some of these issues and previous recommendations for addressing them were described in detail in Monfils and Lee (2007).

Survey Design

Because the objectives of the copperbelly monitoring program include tracking trends in the copperbelly population at known occupied sites and at a broader scale across the sample frame, sites were stratified into samples of recent and historic or unknown occupancy status. All recent or known occupied sites will be surveyed every year (assuming resources are available and access to sites is granted). The remainder of survey sites (i.e., historic or unknown occupancy sites starting with sites with high HSI scores) in a given year will be surveyed in the order they were randomly drawn. Sites will be surveyed using a standard repeat survey design. Surveying an adequate number of historic or unknown occupancy sites in addition to known occupancy sites is critical for producing population parameter estimates and trends that not biased and are representative of the entire population (MacKenzie et al. 2006). Survey results from 2011 suggest that it may be challenging to monitor an adequate number of unknown/historic occupancy sites after all known occupied sites are surveyed using a standard repeat survey design given limited funding, personnel, and other constraints. A larger number of historic/unknown sites needs to be surveyed as part of the copperbelly monitoring program. Increased resources could help address this issue. A different study design (e.g., a mixed model study design), and/or changes to the survey protocol or methods also may need to be considered to help address this issue if it persists.

The number of survey visits to conduct at each site may need to be revisited. MacKenzie and Royle (2005) provided guidance on the optimum number of visits to conduct and sites to survey given levels of occupancy, detectability, and precision. Using occupancy (0.17 – 0.31) and detection probability (0.40 – 0.59) estimates from 2005 and 2006, we estimated that between 2-4 surveys would need to be conducted at each site based on our occupancy and detection probability estimates and guidelines provided by MacKenzie and Royle (2005). Field et al. (2005) found that 2-3 surveys appeared to be sufficient for most species, unless occupancy levels were high or detection probability low. MacKenzie and Royle (2005) also recommended that three visits be considered the minimum when detection probability is greater than 0.50. Given this recommendation and the preliminary nature of our population parameter estimates, we suggested conducting three visits per site in a copperbelly monitoring program (Monfils and Lee 2011). Because the number of survey visits required per site increases as occupancy increases and detectability decreases (MacKenzie and Royle 2005), the number of survey visits to conduct at each site may need to increase given lower detection probability estimates in 2011. Using occupancy (0.19 to 0.38) and detection probability (0.20 to 0.44) estimates from 2011, the optimum number of survey visits per site ranged from 4 to 8 based on guidelines provided by MacKenzie and Royle (2005). However, the number of survey visits to conduct at each site should be decided in the context of the number of sites to be visited, desired precision levels for estimates, total survey effort, and budgetary and personnel limitations. MacKenzie and Royle (2005) also suggested that for rare species one should survey more sites less intensively. Based on the number of sites to be visited, budgetary and personnel limitations, and preliminary nature of our occupancy estimates, we suggest continuing to conduct three survey visits per site at this time. However, this should be revisited in the near future as more data are accumulated and our parameter estimates improve or become more precise.

If detection probability is lower than initially estimated, the number of survey sites needed to detect trends and achieve certain levels of precision also may be impacted. Using an occupancy estimate of about 0.20 and detectability of 0.50-0.60 based on the 2005 and 2006 data, we estimated between 110 and 230 sites would be needed to achieve moderate levels of precision (Monfils and Lee 2011). If detectability is lower than 0.50 and 0.60 based on the 2011 results, and the number of survey visits is constrained, more sites would be needed to detect trends at moderate levels of precision. However, the most important factor influencing trend estimation appears to be the number of sites surveyed in a given season rather than the total number of sites surveyed (MacKenzie 2005). If the number of sites visited each season is limited by resource constraints, then a longer amount of time will be needed to provide trend information (MacKenzie 2005). For these reasons, we continue to suggest using a design in which the maximum number of sites possible is surveyed each year.

Other Design Considerations

Monfils and Lee (2011) provided several additional monitoring design recommendations related to standardizing other aspects of the Copperbelly Water Snake monitoring program, such as the timing of survey periods, number of observers, pattern of site visits, and survey methods. The initial survey season and survey windows were adjusted slightly during and after the 2011 surveys to match survey periods used for the 2005 and 2006 analysis to facilitate comparisons across all three years and in the future. We had some issues in 2011 with visiting each site during each survey window which resulted in missing data. Every effort should be made in the future to visit each site during each survey window to minimize missing observations.

To reduce possible heterogeneity in detection probabilities, Monfils and Lee (2011) also suggested standardizing the number of observers conducting surveys (e.g., one surveyor per site). Sites in 2011 were surveyed primarily by a single observer per site. On a few occasions, two observers surveyed wetland complexes and individual wetlands together by splitting up individual wetlands and having each observer survey half of each wetland. This approach seemed to work quite well, and seemed to shorten the survey time at wetland complexes. Having two surveyors at a site may be considered to help reduce the time needed to complete each survey which could help us survey more sites. Monfils and Lee (2011), based on MacKenzie et al. (2004a), suggested rotating observers among all sites to maximize the independence of surveys. Monfils and Lee (2011) also suggested rotating the order in which the sites are surveyed could reduce possible confounding effects of survey site and time of day on detectability. Rotating observers among sites was not implemented in 2011 and may be logistically difficult and impractical, especially given funding constraints. However, rotating the order in which sites are surveyed is feasible and should be attempted in the future.

Monfils and Lee (2011) recommended that survey methods (e.g., survey routes, observation points) should be consistent among all sites. To reduce variability in the number or proportion of wetlands and types of wetlands surveyed within and across wetland complexes, some rules or guidelines should be developed to standardize the number or proportion of wetlands and the types of wetlands that should be surveyed within a wetland complex. Surveyors also should visit some sites together prior to field surveys to develop or ensure a common understanding of the types of wetlands within a complex that could or should be surveyed and survey methods.

Future Analyses

As Monfils and Lee (2011) recommended, the multi-season occupancy model developed by MacKenzie et al. (2003) and the single-season abundance models (e.g., Royle and Nichols 2003, Royle 2004) provide useful information for monitoring copperbellies and should continue to be applied. Site and survey covariates were not included in the 2011 analyses due to time constraints but should be included in future occupancy analyses. Potential site and survey covariates that might be important to determining Copperbelly Water Snake occupancy and detection need to be identified ahead of time so these data can be collected consistently by observers during surveys. By including covariates in future modeling efforts, we could learn what variables appear to greatly affect occupancy and detection probability, which could inform recovery efforts and possible modifications to the monitoring design. In addition to monitoring occupancy and associated parameters, monitoring the locations and status or condition of individual wetlands in which copperbellies have occupied also is important. This information can be used to assess and monitor spatial trends or changes in copperbelly occupancy and distribution, and help guide or target management and conservation efforts.

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LITERATURE CITED

Attum, O., Y. Lee, B. A. Kingsbury. 2009. The status of the northern population of Copper-bellied Watersnake, *Nerodia erythrogaster neglecta*. Northeastern Naturalist 16:317-320.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second Edition. Springer-Verlag, New York, New York.

Field, S. A., A. J. Tyre, and H. P. Possingham. 2005. Optimizing allocation of monitoring effort under economic and observational constraints. Journal of Wildlife Management 69:473-482.

Herbert, N. 2003. Comparative habitat use of two water snakes, *Nerodia erythrogaster neglecta* and *Nerodia sipedon sipedon*, and implications for conservation. M.S. Thesis, Indiana-Purdue University at Fort Wayne, Fort Wayne, Indiana.

Johnson, D.H., J.P. Gibbs, M. Herzog, S. Lor, N.D. Niemuth, C.A. Ribic, M. Seamans, T.L. Shaffer, W. G. Shriver, S.V. Stehman,, and W.L. Thompson. 2009. A Sampling Design Framework for Monitoring Secretive Marshbirds. Waterbirds 32(2):203-215.

Kendall, W. L. 1999. Robustness of closed capture-recapture methods to violations of the closure assumption. Ecology 80:2517-2525.

Kost, M. A., Y. Lee, J. G. Lee and J. G. Cohen. 2006. Habitat characterization and evaluation of community types utilized by Copperbelly Water Snake (*Nerodia erythrogaster neglecta*) in Michigan and northern Ohio. MNFI Report number 2006-02. Submitted to U.S. Fish and Wildlife Service, Region 3 Endangered Species Office, Federal Building, Fort Snelling, Minnesota.

Lee, Y., O. Attum, H. D. Enander, and B. A. Kingsbury. 2007. Population monitoring and habitat characterization for conservation and recovery of the northern population of the Copperbelly Water Snake (*Nerodia erythrogaster neglecta*). MNFI Report Number 2007-04. Submitted to the U. S. Fish and Wildlife Service, Region 3 Endangered Species Office, Federal Building, Fort Snelling, Minnesota.

MacKenzie, D. I. 2005. What are the issues with presence-absence data for wildlife managers? Journal of Wildlife Management 69:849-860.

MacKenzie, D. I., L. L. Bailey, and J. D. Nichols. 2004b. Investigating species co-occurrence patterns when species are detected imperfectly. Journal of Animal Ecology 73:546-555.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

MacKenzie, D. I., J. D. Nichols, J. E. Hines, M. G. Knutson, and A. B. Franklin. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. Ecology 84:2200-2207.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier Publishing, Inc., Amsterdam, The Netherlands.

MacKenzie, D. I., J. A. Royle, J. A. Brown, and J. D. Nichols. 2004a. Occupancy estimation and modeling for rare and elusive populations. Pages 149-172 *in* W. L. Thompson, editor. Sampling rare or elusive species. Island Press, Washington, D.C.

Mazerolle, M. J., L. L. Bailey, W. L. Kendall, J. A. Royle, S. J. Converse, and J. D. Nichols. 2007. Making great leaps forward: accounting for detectability in herpetological field studies. Journal of Herpetology 41:672–689.

Monfils, M. J., and Y. Lee. 2011. Estimating population parameters for the northern population of Copperbelly Water Snake (*Nerodia erythrogaster neglecta*) to inform conservation and monitoring. Michigan Natural Features Inventory, Report Number 2011-02. Submitted to the U.S. Fish and Wildlife Service, Region 3 Endangered Species Office, Federal Building, Fort Snelling, Twin Cities, Minnesota.

Roe, J. H., B. A. Kingsbury, and N. R. Herbert. 2003. Wetland and upland use patterns in semi-aquatic snakes: implications for wetland conservation. Wetlands 23:1003-1014.

Roe, J. H., B. A. Kingsbury, and N. R. Herbert. 2004. Comparative water snake ecology: conservation of mobile animals that use temporally dynamic resources. Biological Conservation 118:79-89.

Royle, J. A. 2004. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60:108-115.

Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84:777-790.

Stevens, D. L. and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99: 262-278.

U.S. Fish and Wildlife Service. 1997. Endangered and threatened wildlife and plants; determination of threatened status for the northern population of the copperbelly water snake. Final Rule. Federal Register 62(19): 4183-4192. January 29, 1997.

U.S. Fish and Wildlife Service. 2008. Northern Population Segment of the Copperbelly Water Snake (*Nerodia erythrogaster neglecta*) Recovery Plan. Fort Snelling, Minnesota.

APPENDICES

APPENDIX 1

Summary of Occupancy Modelling Results and Monitoring Recommendations Based on 2005-2006 Copperbelly Surveys in Michigan and Ohio

From: Monfils and Lee 2011

Occupancy estimates – range 0.17 - 031

- Single-season Models
    - Single-season occupancy model 2005 – 0.17
    - Abundance-induced heterogeneity model 2005 – 0.17
    - N-mixture repeated count model 2005 – 0.31
    - Single-season occupancy model 2006 – 0.31
- Multiple-season Models
    - 2005 – two models - 0.22 and 0.19
    - 2006 – two models - 0.22 and 0.25

Detection Probability Estimates – range 0.40 – 0.59

- Single-season Models
    - Single-season occupancy model 2005 – 0.58
    - Abundance-induced heterogeneity model 2005 – 0.55
    - N-mixture repeated count model 2005 – 0.40
    - Single-season occupancy model 2006 – 0.46
- Multiple-season Models
    - 2005 & 2006 – both models – 0.59

Site Selection

- We suggest using a probabilistic design (e.g., simple random, stratified random, generalized random tessellation sampling) to facilitate application of the results beyond the sites surveyed.
- We add that focusing a monitoring program on recently or historically occupied sites could produce results and trends not representative of the entire population.
- We suggest stratifying sites by known and unknown historic occupancy status.
- To minimize risk of violating closure assumption, suggest using a minimum separation distance (e.g., 450-500 m) to separate wetland monitoring sites and reduce the potential effects of snake movements on population estimates.

Survey Design

- We believe the standard repeat survey design would be most appropriate.
- We suggest conducting three visits per site.
- Assuming occupancy of about 0.20, detectability of 0.50-0.60, and three surveys per site, we estimate between 110 and 230 sites would be needed to achieve moderate levels of precision (15-20% CV).
    - 110-130 sites to achieve a coefficient of variation (CV) of about 20%
    - 200-230 sites for a CV of approximately 15%
    - (70-80 sites for a CV of 25%)
- We suggest a design which tries to maximize the number of sites surveyed each year rather than trying to maximize the total number of sites surveyed.

Survey Protocol

- Timing of survey periods
    - If a repeat survey approach is used, timing of the surveys should be consistent among all sites.
    - Survey period should be selected to minimize the movement of snakes into or out of sites (i.e., minimize likelihood of violating closure assumption).
    - Survey windows need to be identified for each replicate visit, so that surveys are done at approximately the same time at all sites.
    - Every effort should be made to visit each site during each survey window to minimize missing observations.
- Number of observers
    - To reduce possible heterogeneity in detection probabilities, we suggest standardizing the number of observers conducting surveys (e.g., one surveyor per site).
- Pattern of site visits
    - We suggest rotating observers among all sites to maximize the independence of surveys.
    - We also think rotating the order in which the sites are surveyed could reduce possible confounding effects of survey site and time of day on detectability.
- Survey methods
    - Care should be taken to ensure that the methods (e.g., survey routes, observation points) used to survey snakes are consistent among all sites.
- Covariates
    - We suggest identifying potential site and survey covariates that might be important to determining Copperbelly Water Snake occupancy and detection, and collecting these data consistently during surveys.
    - Suggested covariates – recommend collect data on 2-3 site and survey covariates
        - Site – wetland type, size, presence of buttonbush, canopy cover, distance to roads, surrounding landscape
        - Survey – air temp, water temp, sun/cloud cover

APPENDIX 2

Page ______ of ______

Copperbelly Water Snake Monitoring Data Sheet

Survey Date: __________ **Site name:** ______________________________ **Surveyors:** ______________________________

Overall Visit Start Time: __________ **Wetland Group ID:** ______________________________ **T, R, S:** ______________________________

Overall Visit End Time: __________ **Status of Complex:** Recent, Hist, Unk, High HS,I Low HIS **County:** ______________________________

Survey Duration: __________ **Survey Visit # (circle):** 1 2 3

Total Distance/Perimeter (m):

Summary of Species:	CWS	NWS	Other species:		
Number:					

Beginning Weather: **ir temp (^{o}F):** __________ **Sky Code:** __________ **Wind Code:** __________ **Precipitation Code:** __________

Ending Weather: **ir temp (^{o}F):** __________ **Sky Code:** __________ **Wind Code:** __________ **Precipitation Code:** __________

Start time	End time	Wetland ID #	Water level (Full, Low, Dry)	Species observed	# observed	Latitude/ UTM-X 83 69…	Longitude/ UTM-Y 462…	Photo ID #	Community/ shoreline habitat type/ description	Comments: behavior, habitat, angle and direction if needed

MAFIA, 10/01/2011

Sky Codes:

0 = Sunny/clear to few clouds (0-5% cloud cove

1 = Mostly sunny (5-25% cloud cover)

2 = Partly cloudy, mixed or variable sky (25-50%

3 = Mostly cloudy (50-75%)

4 = Overcast (75-100%)

5 = Fog or haze

Wind Codes (Beaufort wind scale):

0 = Calm (< 1 mph) smoke rises vertically

1 = Light air (1-3 mph) smoke drifts, weather vane inactive

2 = Light breeze (4-7 mph) leaves rustle, can feel wind on face

3 = Gentle breeze (8-12 mph) leaves and twigs move, small flag extends

4 = Moderate breeze (13-18 mph) moves small tree branches, twigs & leaves, raises loose paper

5 = Strong breeze (19-24 mph) small trees sway, branches move, dust blows

6 = Windy (> 24 mph) larger tree branches move, whistling

Precipitation Codes:

0 = None

1 = Mist

2 = Light rain or drizzle

3 = Heavy rain

4 = Snow/hail

General Habitat Types(NWI) (can use other habitat types or descriptions as well):

PFO = Palustrine Forested Wetland: standing water at least part of the year, tree canopy cover exceeds 30%.

PSS = Palustrine Scrub-Shrub Wetland: shrub cover exceeds 30%, but tree cover does not.

SDG = Palustrine Emergent Wetland dominated by sedges.

CAT = Palustrine Emergent Wetland dominated by cattails.

UFO = Upland Forest: >30% tree canopy cover, elevated above any potential flooding by sloping topography.

USS = Upland Scrub-Shrub: berry bushes, willows, crab apples and hawthorns, typically mid-succession.

OLD = Oldfield: fallow fields covered with herbaceous or grassy cover, includes CRP lands.

(Note: Wetland ID # = Wetland_ID_num)

Directions to survey site and location if first time to site/location and/or additional or special comments about access to wetland complex:

Draw or attach map, air photo or drawing indicating survey area, survey routes and locations of copperbellies, and/or suitable habitat if needed for clarification.