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

Prepared by:
Yu Man Lee and Bruce A. Kingsbury

Michigan Natural Features Inventory
P.O. Box 13036
Lansing, MI 48901-3036

For:
U. S. Fish and Wildlife Service
East Lansing Ecological Services Field Office
2651 Coolidge Road
East Lansing, Michigan 48823

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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, 2012, and 2013 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 15 April and 20 June in 2011, 2012, and 2013 at a total of 207 wetlands in 30 different 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 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, 2012 and 2013 survey data were compared with estimates generated from similar collected in 2005 to examine potential trends and evaluate and refine the copperbelly monitoring protocol.

Surveys from 2011-2013 documented a total of 73 Copperbelly Water Snake detections in 7 of the 30 wetland complexes surveyed and 20 of the 207 wetlands surveyed. The occupancy models using the 2011, 2012 and 2013 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 0.08 to 0.38, with most models estimating occupancy between 0.08 and 0.20. Detection probabilities ranged from 0.19 to 0.83, with most detection probabilities between 0.20 and 0.38. The multiple-season model generated occupancy estimates of 0.11 to 0.15, and a detection probability of 0.34. Occupancy estimates in 2012 and 2013 were similar to estimates generated using the 2011 and 2005 data, but detection probability estimates were lower than those generated using the 2005 data. Population parameter estimates and their application and monitoring design recommendations were examined based on monitoring results to date and discussed. Additional monitoring recommendations were provided.

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INTRODUCTION

The northern population segment of the Copperbelly Water Snake (*Nerodia erythrogaster neglecta*) has been listed by the U. S. Fish and Wildlife Service (USFWS) as a federally threatened species (USFWS 2008). The northern copperbelly population is known from only 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 shallow margins of open waterbodies or wetlands (Herbert 2003, Kingsbury et al. 2003, Lee et al. 2005 and 2007, USFWS 2008). Copperbelly Water Snakes also use upland habitats, particularly forested uplands, for foraging, aestivating, hibernating, and traveling among wetlands (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 and 2004). Habitat loss, degradation, and fragmentation are viewed as the primary threats to the Copperbelly Water Snake (USFWS 1997 and 2008).

To inform planning and implementation of conservation and recovery efforts for the northern population segment 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 2005, MacKenzie et al. 2004a and 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 and 2003, Royle and Nichols 2003, Royle 2004). Occupancy modeling may be a useful approach to incorporate into a long-term monitoring program because it can be used to estimate population parameters that can be tracked over time without the need for more intensive studies, and it 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 in 2011 to reanalyze previous 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 occupancy 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/or 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 more targeted or intensive monitoring efforts will likely be needed to fully address these objectives.

This report summarizes the results of the copperbelly surveys conducted in 2012 and 2013 to continue monitoring the northern copperbelly population using occupancy modeling and the monitoring protocol that was developed and implemented in 2011. Monitoring results from 2011 also are included in this report for comparison and to provide an overall summary of monitoring results. The field surveys and associated results from 2012 and 2013 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.

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 known recent distribution and a portion of the historical distribution of the northern population segment of the Copperbelly Water Snake. 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 community types commonly found in the study area include 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 sampling frame for the copperbelly monitoring program consisted of wetland complexes within 400 meters (0.25 mi) of recent (i.e., copperbellies last observed since 2000) and historical (i.e., copperbellies last observed prior to 2000) copperbelly occurrences, and wetland complexes within 5 km (3 mi) of these complexes within the study area. The wetland complexes were identified and delineated by the Copperbelly Water Snake Habitat Suitability Index (HSI) model developed by the USFWS. The model defined a wetland complex as a cluster of wetlands identified and mapped by the National Wetland Inventory (NWI) within 200 m (0.12 mi) of each other and not bisected or separated by paved roads (Kahler pers. comm.). Each wetland complex in the habitat suitability index (HSI) model was given a HSI score based on the average HSI score for individual wetlands within the complex. Habitat suitability index (HSI) scores ranged from 0 to 1, with a score of 1 indicating highest habitat suitability and a score of 0 indicating lowest habitat suitability for copperbellies according to the model.

Wetland complexes included in the sampling frame were stratified and selected for surveys based on their copperbelly occupancy status and HSI score. Wetland complexes that contained wetlands with copperbelly sightings since or post-2000 were classified as ‘recent’ wetland complexes. Sixteen wetland complexes were initially classified as recent wetland complexes. The wetland complex immediately south of where a dead copperbelly was found on the road at a new site in 2010 was added to the list of recent wetland complexes in 2011, resulting in a total of 17 recent wetland complexes. All recent wetland complexes were selected for sampling for the monitoring program, regardless of their HSI score.

The remaining wetland complexes were classified as ‘historical’ or ‘unknown’ wetland complexes. ‘Historical’ wetland complexes were those containing wetlands with copperbelly sightings prior to 2000. ‘Unknown’ wetland complexes were those in which copperbellies have not observed or reported. Of the wetland complexes classified as ‘historical’ or ‘unknown,’ only those with HSI scores greater than or equal to 0.60 were selected for sampling for the monitoring program. This resulted in 168 wetland complexes selected for sampling in the study area. These wetland complexes were further 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 complexes had HSI scores between 0.60 and 0.75. This resulted in 55 historical and unknown wetland complexes classified as ‘high HSI,’ and 113 historical and unknown wetland complexes classified as ‘low HSI.’ With the 17 recent wetland complexes, this resulted in a total of 185 wetland complexes that were selected for sampling for the copperbelly monitoring program. Additionally, a few wetland complexes with HSI scores <0.60 that were associated with recent or historical copperbelly occurrences and were of particular interest were included as sample sites.

Wetland complexes were surveyed or scheduled for surveys based on a mixed panel or mixed model stratified sampling design. Recent wetland complexes were surveyed or targeted for surveys every year copperbelly monitoring was conducted. Historical and unknown wetland complexes classified as ‘high HSI’ or ‘low HSI’ were randomly drawn sequentially and prioritized 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 or drawn for sampling using the R software package. The GRTS sampling design produced an ordered list of ‘high HSI’ and ‘low HSI’ wetland complexes that were surveyed in order of selection depending on access and available time and resources. Wetland complexes classified as ‘high HSI’ were surveyed or targeted for surveys prior to wetland complexes classified as ‘low HSI.’ Once a ‘high HSI’ or ‘low HSI’ wetland complex was surveyed, it was generally not surveyed the following year or in subsequent years until all the remaining ‘high HSI’ and ‘low HSI’ wetland complexes were surveyed, unless a wetland complex was of particular interest for some reason. If a copperbelly was detected in a ‘high HSI’ or ‘low HSI’ historical or unknown wetland complex, the complex would be added to the list of recent wetland complexes, and would be surveyed annually in all subsequent years of the monitoring program along with the other recent wetland complexes.

Wetland complexes selected for sampling contained multiple wetlands, ranging from 1 to 62 individual NWI mapped wetlands. The mean number of NWI wetlands within wetland complexes ranged from about 8-12 wetlands per complex, and the median number of wetlands ranged from about 6-7 wetlands per complex (Kahler pers. comm.). Surveyors selected a subset of wetlands within the wetland complexes to survey. Wetlands known or likely to harbor copperbellies or provided suitable habitat for 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

Visual encounter surveys were conducted at individual wetlands within wetland complexes to detect the presence of Copperbelly Water Snakes. Visual surveys were conducted by walking slowly along the entire length of the shoreline of a wetland or waterbody, 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 locations around the wetland offering the best views. Surveys were generally conducted by one observer within a given wetland complex. On several occasions, two observers conducted surveys together 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 and 2011). In 2012 and 2013, sites in Michigan were surveyed by Yu Man Lee with the MNFI and staff from the USFWS office in East Lansing. Sites in Ohio and Indiana were surveyed by Dr. Bruce Kingsbury and his students at IPFW. New surveyors received training on the monitoring protocol prior to conducting surveys.

In 2012 and 2013, we surveyed and monitored for Copperbelly Water Snakes at a total of 156 wetlands within 26 wetland complexes (see Appendix 2 for list of complexes surveyed). These were comprised of 16 recent wetland complexes (i.e., copperbellies had been observed in the complex since 2000) and 10 wetland complexes classified as 'unknown' or 'historical' (Appendix 1). Two of the complexes were not included in the original list of sample sites, but were surveyed opportunistically. Thirteen of the recent wetland complexes and one of the unknown complexes were surveyed in both 2012 and 2013 (Appendix 1). Of the 156 wetlands surveyed in 2012 and/or 2013, 91 wetlands (58%) were located in recent wetland complexes, and 65 (42%) were located in unknown wetland complexes. Eighty wetlands (51%) were surveyed in both 2012 and 2013. Fifteen (58%) of the 26 wetland complexes and 92 (56%) of the 156 wetlands that were surveyed in 2012 and/or 2013 also were surveyed in 2011.

In 2012, we surveyed a total of 110 wetlands within 16 wetland complexes (Table 1 and Appendix 1). Of the wetland complexes surveyed, 13 were recent wetland complexes, and 3 were classified as 'unknown' and 'high HSI' wetland complexes (Appendix 1). Due to time and personnel constraints and lack of landowner permission or access, only 13 of the 17 recent wetland complexes were surveyed in 2012. One additional wetland was visited but not surveyed in 2012 because it did not provide suitable copperbelly habitat.

In 2013, we surveyed a total of 124 wetlands within 24 wetland complexes (Table 1). These included two wetland complexes classified as 'unknown' that were not originally included in the study sample but were surveyed because one of them was immediately adjacent to a recent wetland complex, and copperbellies had been reported from the other complex (Appendix 2). Two of the recent wetland complexes that were surveyed in 2013 had not been previously surveyed in 2011 or 2012, and one complex had been surveyed in 2011 but not in 2012 (Appendix 2). Two of the unknown wetland complexes surveyed in 2013 had been previously surveyed in 2011 or 2012 and were of particular interest because they were adjacent to or near wetland complexes with recent copperbelly occurrences or reports (Appendix 2). Three additional wetlands were examined in the field but did not provide suitable copperbelly habitat and were not surveyed.

Overall, a total of 207 wetlands within 30 different wetland complexes were surveyed and monitored for copperbellies from 2011 to 2013 (Table 1 and Appendix 1). These included 16 of the 17 recent wetland complexes, of which 13 were surveyed in all three years (Appendix 2). Of the 14 wetland complexes classified as ‘unknown’ that were surveyed during 2011-2013, 12 complexes had high HSI scores (HSI ≥0.75), and 2 had low HSI scores (HSI <0.75). A total of 67 wetlands (32%) were surveyed during all three years, and 38 wetlands (18%) were surveyed during two of the three years.

Table 1. Summary of survey effort for Copperbelly Water Snake monitoring of recent and unknown/historical wetland complexes in Indiana, Ohio, and Michigan from 2011-2013.

	2011	**2012**	**2013**	**Overall 2011-2013**
Number of wetland complexes surveyed	19	16	24	30
Number of recent wetland complexes	14	13	16	16[a]
Number of unknown/historical complexes	5	3	8	14
Number of individual wetlands surveyed	137	110	124	207[b]
Number of wetlands surveyed in recent wetland complexes	102	78	83	113
Percent of total wetlands surveyed that were in recent wetland complexes	74%	71%	67%	55%
Number of wetlands surveyed in unknown/historical wetland complexes	35	32	41	94
Percent of total wetlands surveyed that were in unknown/historical wetland complexes	26%	29%	33%	45%
Minimum # of wetlands surveyed/complex	3	2	2	2
Maximum # of wetlands surveyed/complex	9 (16)[c]	9 (21)[c]	9	9 (21)[c]
Mean # of wetlands surveyed/complex	7	7	5	7

[a]Only 1 recent wetland complex (G4087) was not surveyed during 2011-2013.
[b]This total does not include 6 wetlands that were visited during surveys in 2011-2013 but were not suitable copperbelly habitat and 1 additional wetland that was not part of the study sample.
[c]Maximum number of wetlands surveyed per complex was 9 for most wetland complexes surveyed in 2011 and 2012 except for 2 complexes in 2011 (max = 13 and 16) and 1 complex in 2012 (max = 21).

The monitoring protocol stipulated three survey visits to each wetland complex and individual wetland selected for surveys, with each of the three survey visits occurring in a specified time period to control for the effect of survey timing. The three survey time periods utilized for the surveys in 2012 and 2013 consisted of the following: (1) April 15 to May 10; (2) May 11 to May 31; and (3) June 1 to June 20. These were the same time periods used for the surveys in 2011. These survey periods were selected to coincide with typical changes in weather and vegetation conditions that might affect snake activity, our visibility in the wetlands, and snake detectability. Three survey visits were conducted at all of the wetland complexes monitored in 2012, and all but two of the wetland complexes monitored in 2013. Most individual wetlands within the complexes were surveyed three times during the monitoring period in 2012 and 2013, with a small number of wetlands surveyed only twice (i.e., 5 wetlands in 2012, 5 wetlands in 2013) or once (i.e., 6 wetlands in 2013) during the monitoring period.

During each survey visit, observers recorded survey location, survey visit number (i.e., visit #1, 2, or 3), date, survey start and end times, water level, general wetland or shoreline habitat type and description, the number of copperbellies observed, and species and number of other snakes and herps observed (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, copperbelly observations, and observations of other rare herp species using GPS units. Copperbelly and other rare herp observations documented during surveys in Michigan from 2012-2013 were entered into the Michigan Natural Heritage Database to update Copperbelly Water Snake element occurrence records in the database. Information regarding copperbelly and other rare herp observations documented in Ohio and Indiana will be provided to the Ohio Department of Natural Resources and Indiana Department of Natural Resources.

Data Analysis

We used models available in PRESENCE 3.1 (http://www.mbr-pwrc.usgs.gov/software/presence.shtml) to estimate and monitor population parameters for the northern population segment 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 occupancy modeling. Under this scenario, we assumed 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 included or available at this time, so we only used simple models lacking covariates. We used the same models used by Monfils and Lee (2011) to analyze the 2005, 2006, and 2011 copperbelly survey data to analyze the 2012 and 2013 data to allow comparisons between the results. A discussion of the assumptions of the models used in our analyses is provided 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 2012 and 2013 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). We ran one set of single-season models with data from all wetlands surveyed in recent and unknown wetland complexes, and another set of models with data from only wetlands surveyed in recent wetland complexes.

Two recently developed modeling methods (Royle and Nichols 2003, Royle 2004) built upon the single-season model developed by MacKenzie et al. (2002) allow for 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 2012 and 2013 data to provide coarse Copperbelly Water Snake abundance estimates. More importantly, these estimates can be used to examine and monitor population trends over time. We ran one set of abundance models with data from all wetlands surveyed, and another set with data only from wetlands surveyed in recent wetland complexes.

Single-season model results from 2012 and 2013 were compared with model results generated from the 2011 data to evaluate and monitor population parameter estimates. We generated new single-season models from the 2011 data because we removed 11 wetlands from the analysis (i.e., wetlands that were suitable copperbelly habitat, wetlands that were surveyed in 2005/2006 but not in 2011). Model results from 2012 and 2013 also were generally compared with model results generated from copperbelly survey data from 2005 to provide some additional insight into population parameters and potential trends. The 2012 and 2013 model results could be compared with the 2005 results because the number and locations of sites surveyed in 2012 and 2013 were similar to those surveyed in 2005, particularly related to recent wetland complexes and wetlands. However, the 2012 and 2013 model results could not be compared with model results generated from the 2006 copperbelly dataset because the available dataset was much smaller and only included survey data from only three wetland complexes in Michigan.

Multiple-season Models

We also used a multiple-season occupancy model developed by MacKenzie et al. (2003) to analyze the 2011, 2012, and 2013 copperbelly survey data. This analysis included data from all wetland complexes and a separate analysis for just the recent wetland complexes that were surveyed in or across 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 multiple-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

Overall, surveys from 2011-2013 documented a total of 73 Copperbelly Water Snake observations or detections in 20 individual wetlands in 7 different wetland complexes (Table 2). Surveys in 2012 and 2013 documented a total of 41 Copperbelly Water Snake observations or detections in 15 individual wetlands in 7 different wetland complexes (Table 2). In 2012, a total of 25 copperbelly observations were documented in 12 different wetlands across 7 wetland complexes. In 2013, 16 copperbelly observations were documented in only 7 different wetlands across 4 wetland complexes. Copperbellies were detected in both years in only four of the wetlands and three of the wetland complexes. The seven wetland complexes in which copperbellies were documented in 2012 and/or 2013 were all recent wetland complexes, and all but one of these complexes had high HSI scores (i.e., $\geq$0.75) (Appendix 1). These were the same wetland complexes in which copperbellies were observed during 2011 surveys. Four of these wetland complexes are located in Michigan, two are in Ohio, and one is along the border of Michigan and Ohio (Appendix 1). Surveys in 2012 and 2013 did not document copperbellies at the other nine recent wetland complexes that were surveyed although suitable wetland habitats for copperbellies were still present at many of these sites. Surveys in 2012 and 2013 were still not able to detect copperbellies at a recent wetland complex and a 'high HSI' wetland complex associated with the new copperbelly site documented in Michigan in 2010 although a number of suitable wetland habitats for the copperbelly were found in both these complexes.

Table 2. Summary of Copperbelly Water Snake observations/detections documented during monitoring of recent and unknown/historical wetland complexes in Indiana, Ohio, and Michigan from 2011-2013.

	2011	**2012**	**2013**	**Overall 2011-2013**
Number of Copperbelly Water Snake observations/detections	32	25	16	73
Number of wetland complexes in which Copperbelly Water Snakes were observed/detected	7	7	4	7
Number of wetlands in which Copperbelly Water Snakes were observed/detected	15	12	7	20
Total number of wetlands surveyed	137	110	124	207
Naïve occupancy (# wetlands with copperbelly observations / total number of wetlands surveyed)	0.11	0.11	0.06	0.10

It is important to add that a dead, young copperbelly was found in a small wetland in one of the recent wetland complexes in Michigan in 2012. The snake looked intact, and the cause of death was unknown. Additionally, a copperbelly was found in 2012 that was shedding abnormally or incompletely in one of the wetlands in a recent wetland complex in Michigan. We collected several small samples of shed skin from this snake, and sent the samples to Dr. Matthew Allender with the University of Illinois at Urbana-Champaign for testing for snake fungal disease and the presence of the fungus *Ophidiomyces* (formerly *Chrysosporium*) *ophiodiicola* and other analysis. The tests came back negative for snake fungal disease, but the tests may not have been conclusive because of the nature and the limited amount of sample that was collected.

In addition to Copperbelly Water Snakes, a number of other reptile and amphibians species were observed (i.e., seen or heard) during surveys in 2012 and/or 2013, including several rare species. These include the Northern Watersnake (*Nerodia sipedon sipedon*), Eastern/Northern Ribbonsnake (*Thamnophis sauritus/ Thamnophis sauritus septentrionalis*), Common/Eastern Gartersnake (*Thamnophis sirtalis/ Thamnophis sirtalis sirtalis*), Milksnake (*Lampropeltis triangulum*), Dekay's Brownsnake (*Storeria dekayi*), Painted Turtle (*Chrysemys picta*), Snapping Turtle (*Chelydra serpentina*), Blanding's Turtle (*Emydiodea blandingii*), Eastern Box Turtle (*Terrapene carolina*), Western Chorus Frog (*Pseudacris triseriata*), Green Frog (*Lithobates [Rana] clamitans*), American Bullfrog (Lithobates *[Rana] catesbeianus*), Wood Frog (*Lithobates [Rana] sylvaticus*), Northern Leopard Frog (*Lithobates [Rana] pipiens*), Gray Treefrog (*Hyla versicolor*), Spring Peeper (*Pseudacris crucifer*), American Toad (*Anaxyrus [Bufo] americanus*), Eastern/Blanchard's Cricket Frog (*Acris crepitans/blanchardi*), Spotted Salamander (*Ambystoma maculatum*), and Blue-spotted Salamander (Ambystoma laterale) and/or unisexual hybrid (*Ambystoma laterale* complex). Sixteen observations of Blanding's Turtles, which is a state endangered species in Indiana, a state threatened species in Ohio, and a species of special concern in Michigan, were documented in 10 different wetlands during surveys in 2012 and 2013. Four Common or Eastern Box Turtles, which is a species of special concern in Ohio and Michigan, were found at one site/wetland in Ohio. The Blanchard's Cricket Frog, which is a state threatened species in Michigan, was heard or seen in at least seven different wetlands in three wetland complexes, including a new area from which the species had not been documented. Northern Leopard Frogs, which is listed as a Species of Greatest Conservation Need (SGCN) in Michigan and Indiana's State Wildlife Action Plans, were documented in numerous wetlands in Michigan in 2012 and 2013. Common or Eastern Gartersnakes, which is a species of special concern in Ohio, were recorded from several sites in Ohio. Additionally, Green Frogs and American Bullfrogs were documented in 66 and 35 of the wetlands surveyed, respectively, and Snapping Turtles were documented in 9 of the wetlands.

In 2012, we started to document the presence and number of Northern Water Snakes that were observed and the number of wetlands/wetland complexes in which they were observed during the copperbelly monitoring surveys to provide some perspective on and to compare with Copperbelly Water Snake observations documented during the surveys. In 2012, a total of 114 observations of Northern Water Snakes were documented in 35 wetlands in 12 different wetland complexes (10 recent complexes and 2 unknown/historical complexes). In 2013, a total of 90 Northern Water Snake observations were documented in 32 wetlands in 15 wetland complexes (11 recent complexes and 4 unknown/historical complexes).

Single-season Models

Surveyed Wetlands from Recent and Unknown Wetland Complexes

Using several single-season occupancy models, we estimated low levels of Copperbelly Water Snake site occupancy (i.e., proportion of sites occupied or used) and low detection probabilities based on the 2012 and 2013 data as well as the 2011 data. Burnham and Anderson (2002) stated that models with AIC differences less than two have substantial empirical support. Based on this premise, two models, one with constant occupancy and detection probabilities and the second containing abundance-induced heterogeneity in detection probability (Royle and Nichols 2003), were supported by the 2011 and 2013 data (Tables 3 and 5). However, only one model, the model with detection probability varying among surveys, was supported by the 2012 data (Table 4). This model also seemed to be supported by the 2013 data to some degree (i.e., AIC difference of only 2.41, Table 5).

Although some models seemed to fit the data better, all three single-season models generated very similar occupancy estimates and fairly similar detection probability estimates in all three years (Tables 4, 5, and 6; Figures 1 and 3). 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 4, Figures 1 and 3). Detection probability was similar for the two best-supported models in 2011, 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 4, Figures 4 and 6). The model with variable detection probability among surveys also estimated occupancy at 0.19 (SE=0.06), and detection probability ranging from 0.37 (SE=0.14) for the first survey visit to 0.26 (SE=0.12) for the last survey visit, with an average detection probability of 0.32 (SE=0.13) (Table 4). In 2012, naïve occupancy was 0.11, as in 2011, and the best-approximating model, the variable detection probability model, estimated occupancy at 0.12 (SE=0.03) (Table 5, Figures 1 and 3). Detection probability ranged from 0.83 (SE=0.15) for the first survey visit to 0.38 (SE=0.14) for the second survey visit and 0.23 (SE=0.12) for the third survey visit, and averaged 0.48 (SE=0.14) across all three survey visits (Table 5, Figures 4 and 6). The constant occupancy and detectability model and the abundance-induced heterogeneity model both estimated occupancy at 0.14 (SE=0.04 and SE=0.05, respectively), and detection probability at 0.40 (SE=0.11) and 0.37 (0.12), respectively (Table 5). In 2013, naïve occupancy was 0.06, slightly lower than in 2011 and 2012, and both of the best-approximating models, the constant occupancy and detectability model and the abundance-induced heterogeneity model, estimated occupancy at 0.08 (SE=0.04) (Table 6, Figures 1 and 3). Detection probability was similar for these two models, with an estimate of 0.36 (SE=0.15) for the constant detectability model and 0.35 (SE=0.15) for the abundance-induced heterogeneity model (Table 6, Figures 4 and 6). The variable detection probability model estimated occupancy at 0.07 (SE=0.03) and detection probability ranging from 0.50 (SE=0.24) to 0.22 (SE=0.15) with an average detection probability of 0.39 (SE=0.20) across all three survey visits (Table 6).

The repeated-count models (Royle 2004) also estimated low levels of copperbelly site occupancy and low detection probabilities based on data from all three years, although these models generally produced greater occupancy estimates and lower detection probabilities than the other single-season models (Figures 3 and 6). In 2011, the repeated-count model estimated occupancy at 0.38 (SE=0.12) and detection probability at 0.20 (SE=0.07), whereas the other best-approximating single-season 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=0.38, SE=0.12) and detection probability at 0.32 (SE=0.10) and 0.29 (SE=0.11), respectively (Table 4; Figures 2, 3, 5, and 6). In 2012, the repeated-count model estimated occupancy at 0.26 (SE=0.08) and detection probability at 0.26 (SE=0.09), whereas the other best-approximating single-season model, the variable detectability model, estimated occupancy at 0.12 (SE=0.12), and detection probability ranging from 0.23 (SE=0.12) to 0.83 (SE=0.15) and averaging 0.48 (SE=0.14) (Table 5; Figures 2, 3, 5, and 6). In 2013, the repeated-count model estimated occupancy at 0.21 (SE=0.09) and detection probability at 0.19 (SE=0.10), whereas the other best-approximating single-season models, the constant occupancy and detectability model and the abundance-induced heterogeneity model, estimated occupancy at 0.08 (SE=0.04) and detection probability at 0.36 (SE=0.15) and 0.35 (SE=0.15) (Table 6; Figures 2, 3, 5, and 6).

Similar to the low estimates of occupancy, we obtained low abundance estimates using the Royle and Nichols (2003) and Royle (2004) models, with the Royle (2004) model (i.e., the repeated-count model) generally producing greater abundance estimates than the Royle and Nichols (2003) model (i.e., abundance-induced heterogeneity model) (Tables 4, 5 and 6; Figures 7 and 8). In 2011, total copperbelly abundance for the sites surveyed was estimated at 29.8 (SE=11.8) by the abundance-induced heterogeneity model and 65.3 (SE=25.5) by the repeated-count model (Table 4, Figures 7 and 8). In 2012, total abundance for the sites surveyed was estimated at 17.0 (SE=6.0) by the abundance-induced heterogeneity model and 33.3 (SE=12.0) by the repeated-count model (Table 5, Figures 7 and 8). In 2013, total abundance for the sites surveyed was estimated at 10.3 (SE=4.5) by the abundance-induced heterogeneity model and 29.0 (SE=14.9) by the repeated-count model (Table 6, Figures 7 and 8). Using the abundance-induced heterogeneity model, we estimated average Copperbelly Water Snake abundance at 0.22 (SE=0.09), 0.15 (SE=0.05), and 0.08 (SE=0.04) snakes per site in 2011, 2012, and 2013, respectively. Using the repeated-count model, we estimated average Copperbelly Water Snake abundance at 0.48 (SE=0.19), 0.30 (SE=0.11), and 0.23 (SE=0.12) snakes per site in 2011, 2012, and 2013, respectively.

Table 3. Summary of single-season models used to estimate occupancy (Ψ) and detection probability (*p*) for Copperbelly Water Snake detection-nondetection data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012 and 2013.

Model	ΔAIC	AIC Weight	No. Parameters
2011 (n=137)[1]			
Ψ (.), *p* (.)	0.00	0.4755	2
Ψ (.), *p* (abundance-induced heterogeneity)[2]	0.17	0.4368	2
Ψ (.), *p* (survey-specific)	3.38	0.0877	4
2012 (n=110)			
Ψ (.), *p* (survey-specific)	0.00	0.8881	4
Ψ (.), *p* (.)	5.53	0.0559	2
Ψ (.), *p* (abundance-induced heterogeneity)[2]	5.53	0.0559	2
2013 (n=124)			
Ψ (.), *p* (.)	0.00	0.4358	2
Ψ (.), *p* (abundance-induced heterogeneity)[2]	0.01	0.4336	2
Ψ (.), *p* (survey-specific)	2.41	0.1306	4

[1]Sample size was 145 for earlier analysis in Lee et al. (2011) because it included several wetlands that were surveyed that were not suitable copperbelly habitat, and some wetlands that were surveyed in 2005 and/or 2006 but were not surveyed in 2011. These wetlands were removed from this analysis.

[2]Royle and Nichols (2003) estimator.

Table 4. 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 survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011 (n=137)[1] (in order of AIC difference for first 3 models).

2011	Occupancy					Detection Probability				Total Abundance			
Model	Naïve	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	*N*	SE	LCL	UCL
Single-season Occupancy - constant *p*[2]	0.11	0.19	0.06	0.09	0.34	0.32	0.10	0.16	0.54	NA[3]	NA	NA	NA
Abundance-induced Heterogeneity[4]	0.11	0.20	0.07	0.10	0.38	0.29	0.11	0.08	0.50	29.8	11.8	13.7	64.5
Single-season Occupancy - variable *p*[5]	0.11	0.19	0.06	0.10	0.35	*p1*-0.37, *p2*-0.33, *p3*-0.26, *(0.32)*	0.14, 0.13, 0.12, *(0.13)*	0.15, 0.14, 0.10, *(0.13)*	0.66, 0.61, 0.53, *(0.60)*	NA[3]	NA	NA	NA
N-Mixture Repeated Count[6]	0.11	0.38	0.12	0.20	0.64	0.20	0.07	0.05	0.34	65.3	25.5	30.4	140.2

[1]Sample size was 145 for earlier analysis in Lee et al. (2011) because it included several wetlands that were surveyed that were not suitable copperbelly habitat, and 11 additional wetlands that were surveyed in 2005 and/or 2006 but were not surveyed in 2011. These wetlands were removed from this analysis. The sample size only includes wetlands that were suitable copperbelly habitat and were surveyed 1-3 times in 2011, and does not include wetlands that were surveyed in 2012 and/or 2013 but not in 2011.

[2]MacKenzie et al. (2002) model with best supported model having detection probability constant across surveys.

[3]Parameter is not estimated by the model.

[4]Royle and Nichols (2003) estimator.

[5]MacKenzie et al. (2002) model with variable detection probability among surveys – *p1* for survey visit 1, *p2* for survey visit 2, *p3* for survey visit 3, and average values in parentheses and italics. Model results provided for comparison but model was not well-supported by the data because AIC difference was greater than 2.

[6]Royle (2004) model.

Table 5. 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 survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2012 (n=110)[1] (in order of AIC difference for first 3 models).

2012	Occupancy					Detection Probability				Total Abundance			
Model	Naïve	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	*N*	SE	LCL	UCL
Single-season Occupancy - variable *p*[2]	0.11	0.12	0.03	0.07	0.21	*p1*-0.83, *p2*-0.38, *p3*-0.23, *(0.48)*	0.15, 0.14, 0.12, *(0.14)*	0.36, 0.16, 0.07, *(0.20)*	0.98, 0.66, 0.52, *(0.72)*	NA[3]	NA	NA	NA
Single-season Occupancy - constant *p*[4]	0.11	0.14	0.04	0.07	0.25	0.40	0.11	0.21	0.62	NA[3]	NA	NA	NA
Abundance-induced Heterogeneity[5]	0.11	0.14	0.05	0.07	0.27	0.37	0.12	0.15	0.60	17.0	6.0	8.5	33.9
N-Mixture Repeated Count[6]	0.11	0.26	0.08	0.14	0.46	0.26	0.09	0.07	0.44	33.3	12.0	16.5	67.4

[1]Sample size only includes wetlands that were suitable copperbelly habitat and were surveyed 1-3 times in 2012, and does not include wetlands that were surveyed in 2011 and/or 2013 but not in 2012.

[2]MacKenzie et al. (2002) model with best supported model having variable detection probability among surveys – *p1* for survey visit 1, *p2* for survey visit 2, *p3* for survey visit 3, and average values in parentheses and italics.

[3]Parameter is not estimated by the model.

[4]MacKenzie et al. (2002) model with detection probability constant across surveys. Model results provided for comparison but model was not well-supported by the data because AIC difference was greater than 2.

[5]Royle and Nichols (2003) estimator. Model results provided for comparison but model was not well-supported by the data because AIC difference was greater than 2.

[6]Royle (2004) model.

Table 6. 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 survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2013 (n=124)[1] (in order of AIC difference for first three models).

2013	Occupancy					Detection Probability				Total Abundance			
Model	Naïve	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	*N*	SE	LCL	UCL
Single-season Occupancy - constant *p*[2]	0.06	0.08	0.04	0.03	0.18	0.36	0.15	0.14	0.67	NA[3]	NA	NA	NA
Abundance-induced Heterogeneity[4]	0.06	0.08	0.04	0.03	0.19	0.35	0.15	0.05	0.65	10.3	4.5	4.1	25.9
Single-season Occupancy - variable *p*[5]	0.06	0.07	0.03	0.03	0.17	*p1*-0.50, *p2*-0.44, *p3*-0.22, *(0.39)*	0.24, 0.21, 0.15, *(0.20)*	0.13, 0.13, 0.05, *(0.25)*	0.87, 0.80, 0.62, *(0.76)*	NA[3]	NA	NA	NA
N-Mixture Repeated Count[6]	0.06	0.21	0.09	0.08	0.47	0.19	0.10	-0.01	0.39	29.0	14.9	10.6	79.2

[1]Sample size only includes wetlands that were suitable copperbelly habitat and were surveyed 1-3 times in 2013, and does not include wetlands that were surveyed in 2011 and/or 2012 but not in 2013.

[2]MacKenzie et al. (2002) model with best supported model having detection probability constant across surveys.

[3]Parameter is not estimated by the model.

[4]Royle and Nichols (2003) estimator.

[5]MacKenzie et al. (2002) model with variable detection probability among surveys – *p1* for survey visit 1, *p2* for survey visit 2, *p3* for survey visit 3, and average values in parentheses and italics. Model results provided for comparison but model was not well-supported by the data because AIC difference was greater than 2.

[6]Royle (2004) model.

Table 7. 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 best supported by survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison.

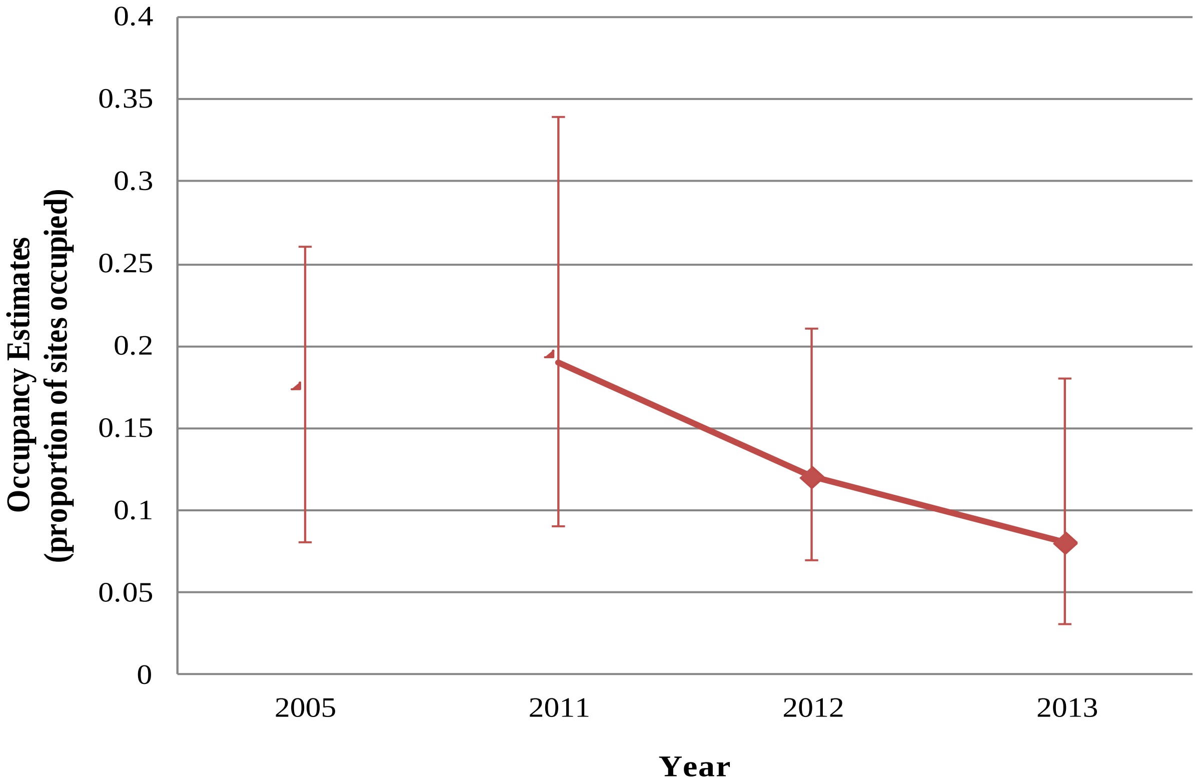
	Occupancy					Detection Probability				Total Abundance			
Models	Naïve	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	*N*	SE	LCL	UCL
2005 (n=105)													
Single-season Occupancy[1]	0.14	0.17	0.04	0.08	0.26	0.58	0.10	0.37	0.78	NA[2]	NA	NA	NA
Abundance-induced Heterogeneity[3]	0.14	0.17	0.04	0.08	0.26	0.55	0.11	0.33	0.77	19.7	5.6	8.6	30.9
2011 (n=137)													
Single-season Occupancy[1]	0.11	0.19	0.06	0.09	0.34	0.32	0.10	0.16	0.54	NA[2]	NA	NA	NA
Abundance-induced Heterogeneity[3]	0.11	0.20	0.07	0.10	0.38	0.29	0.11	0.08	0.50	29.8	11.8	13.7	64.5
2012 (n=110)													
Single-season Occupancy[4]	0.11	0.12	0.03	0.07	0.21	*p1*-0.83, *p2*-0.38, *p3*-0.23, *(0.48)*	0.15, 0.14, 0.12, *(0.14)*	0.36, 0.16, 0.07, *(0.20)*	0.98, 0.66, 0.52, *(0.72)*	NA[2]	NA	NA	NA
Abundance-induced Heterogeneity[3, 5]	0.11	0.14	0.05	0.07	0.27	0.37	0.12	0.15	0.60	17.0	6.0	8.5	33.9
2013 (n=124)													
Single-season Occupancy[1]	0.06	0.08	0.04	0.03	0.18	0.36	0.15	0.14	0.67	NA[2]	NA	NA	NA
Abundance-induced Heterogeneity[3]	0.06	0.08	0.04	0.03	0.19	0.35	0.15	0.05	0.65	10.3	4.5	4.1	25.9

[1]MacKenzie et al. (2002) model, with best supported model having detection probability constant across surveys.
[2]Parameter is not estimated by the model.
[3]Royle and Nichols (2003) estimator.
[4]MacKenzie et al. (2002) model, with best supported model having variable detection probability among surveys. Detection probability, SE, LCL, and UCL estimates for survey visit 1 (*p1*), 2 (*p2*), and 3 (*p3*) and average values (in parentheses and italics) are provided.
[5]Model was not best supported by the data in 2012, but results are provided for comparison.

Table 8. 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 N-mixture repeated count models (Royle 2004) fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison.

	Occupancy					Detection Probability				Total Abundance			
Model[1]	Naïve	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	*N*	SE	LCL	UCL
2005 (n=105)	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
2011 (n=137)	0.11	0.38	0.12	0.20	0.64	0.20	0.07	0.05	0.34	65.3	25.5	30.4	140.2
2012 (n=110)	0.11	0.26	0.08	0.14	0.46	0.26	0.09	0.07	0.44	33.3	12.0	16.5	67.4
2013 (n=124)	0.06	0.21	0.09	0.08	0.47	0.19	0.10	-0.01	0.39	29.0	14.9	10.6	79.2

[1]Results for Royle (2004) model only.



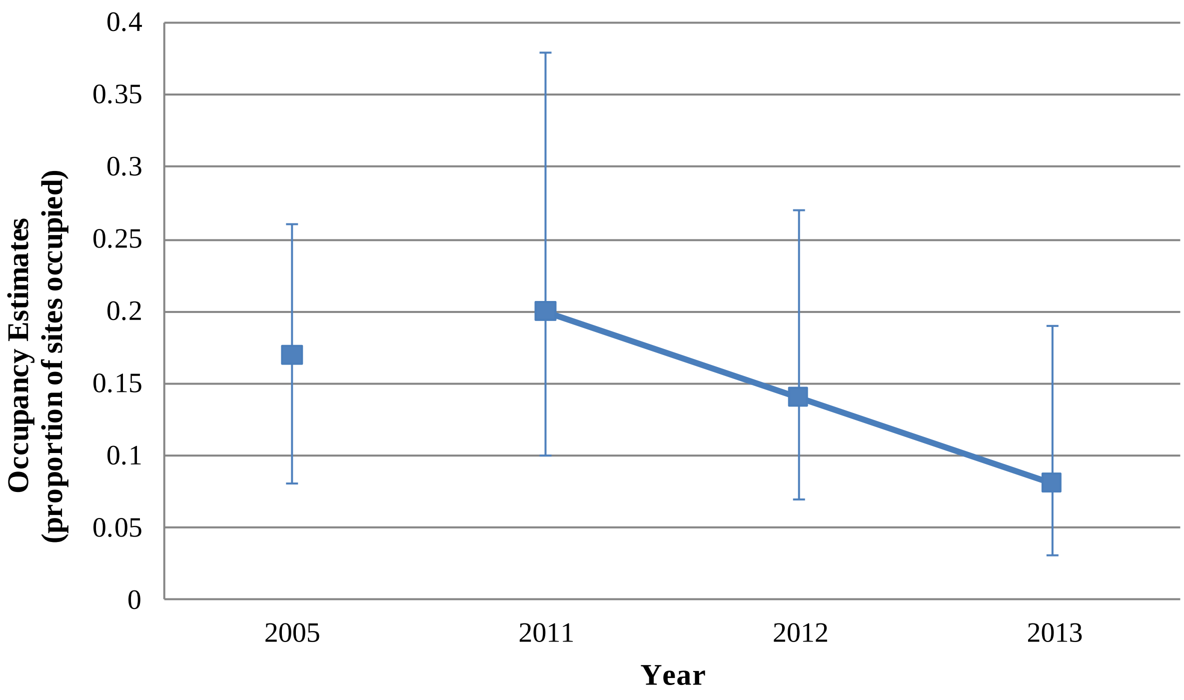


Figure 1. Model-estimated Copperbelly Water Snake occupancy and lower and upper 95% confidence limits (LCL and UCL) based on best-supported single-season occupancy models (MacKenzie et al. 2002) (top graph) and abundance-induced heterogeneity models (Royle and Nichols 2003) (bottom graph) fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison.

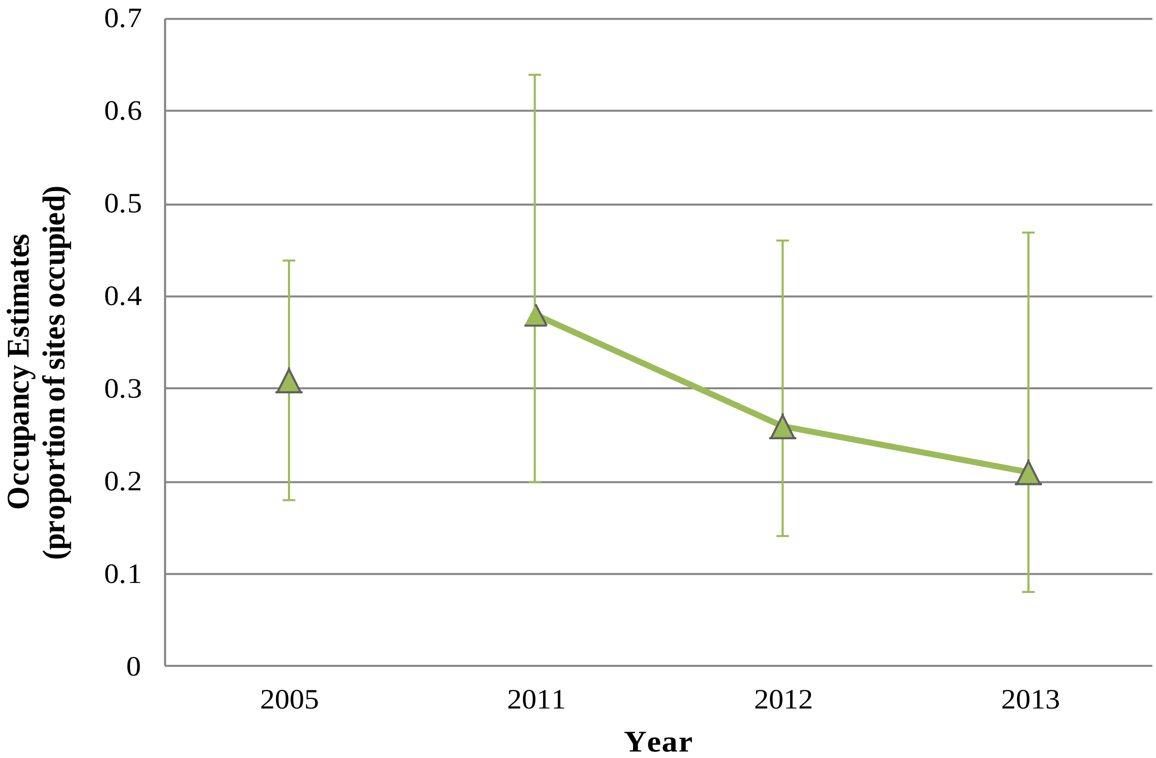


Figure 2. Model-estimated Copperbelly Water Snake occupancy and lower and upper 95% confidence limits (LCL and UCL) based on single-season N-mixture repeated count models (Royle 2004) fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison.

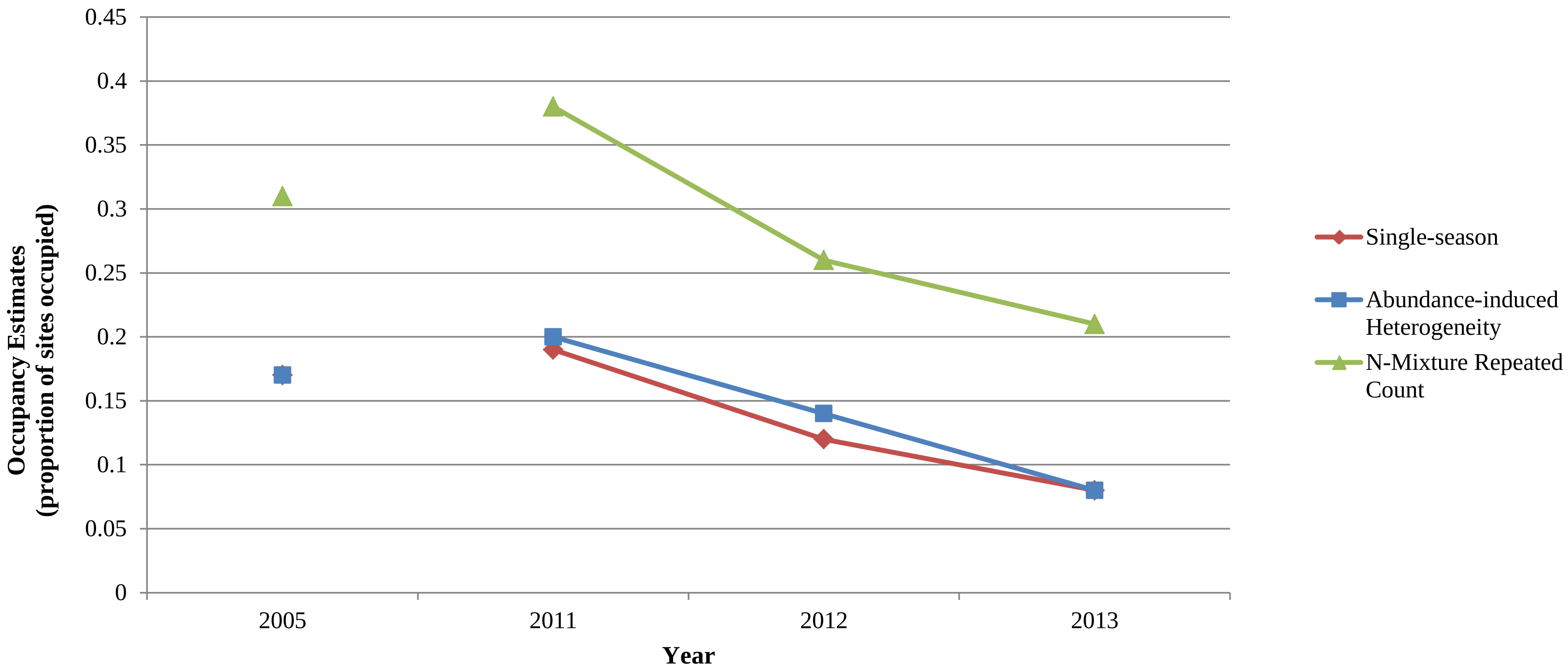
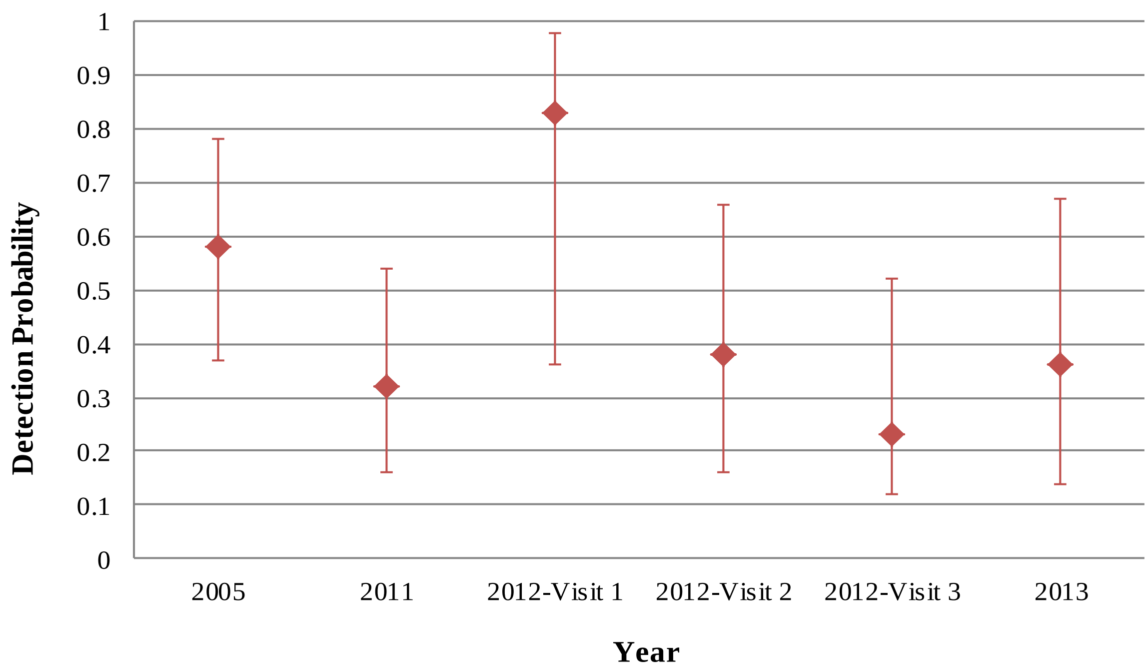


Figure 3. Model-estimated Copperbelly Water Snake occupancy based on best-supported single-season occupancy models (MacKenzie et al. 2002), abundance-induced heterogeneity models (Royle and Nichols 2003), and single-season N-mixture repeated count models (Royle 2004) fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison. Graph provided for general comparison of occupancy estimates across models.



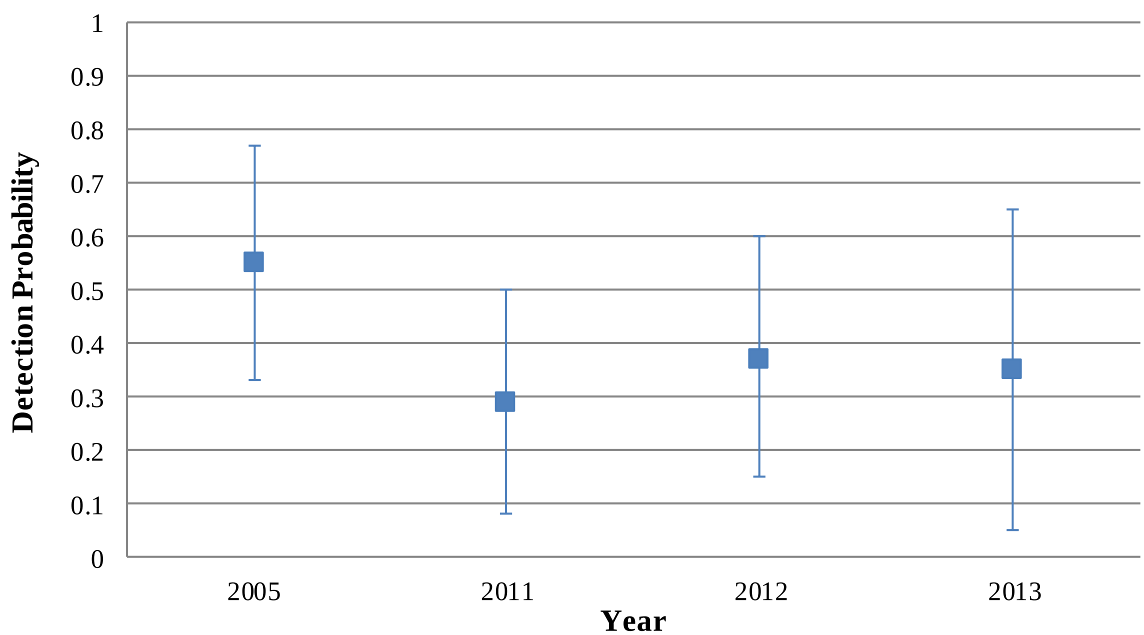


Figure 4. Model-estimated Copperbelly Water Snake detection probability and lower and upper 95% confidence limits (LCL and UCL) based on best-supported single-season occupancy models (MacKenzie et al. 2002) (top graph) and abundance-induced heterogeneity models (Royle and Nichols 2003) (bottom graph) fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison. In 2012, the best-supported single-season occupancy model was the variable detection probability model; hence, detection probability estimates for each survey visit are shown in the top graph.

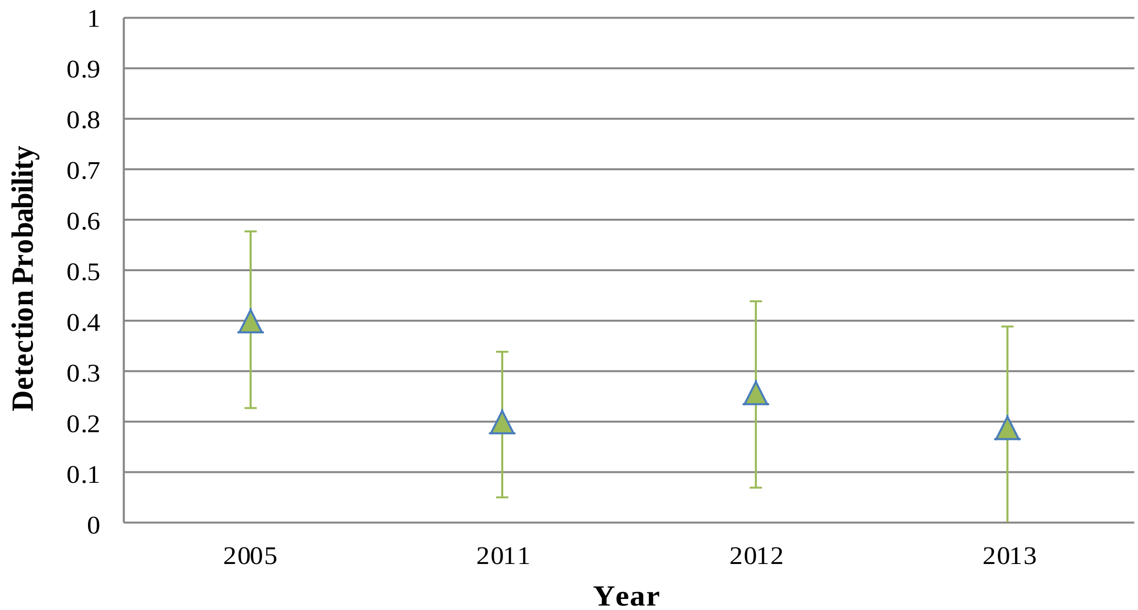


Figure 5. Model-estimated Copperbelly Water Snake detection probability and lower and upper 95% confidence limits (LCL and UCL) based on single-season N-mixture repeated count models (Royle 2004) fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison.

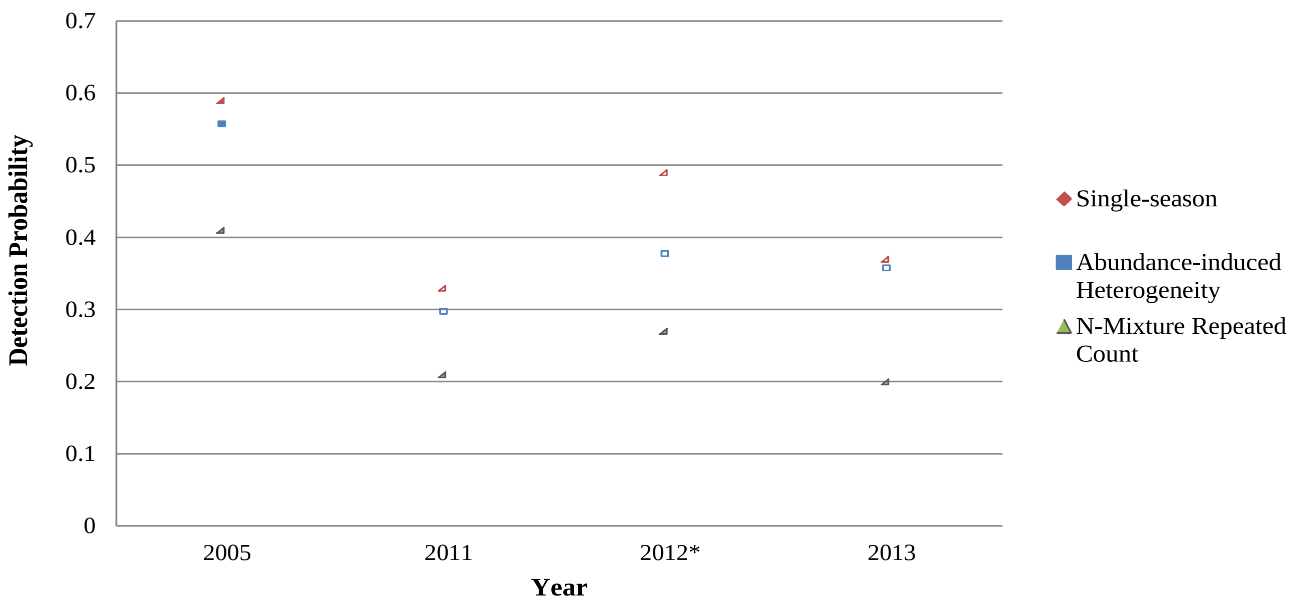


Figure 6. Model-estimated Copperbelly Water Snake detection probability based on best-supported single-season occupancy models (MacKenzie et al. 2002), abundance-induced heterogeneity models (Royle and Nichols 2003), and single-season N-mixture repeated count models (Royle 2004) fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison. Graph provided for general comparison of detection probability estimates across models. The detection probability estimate for the single-season occupancy model in 2012 shown in this graph represents an average of the detection probability estimates for all three survey visits in 2012.

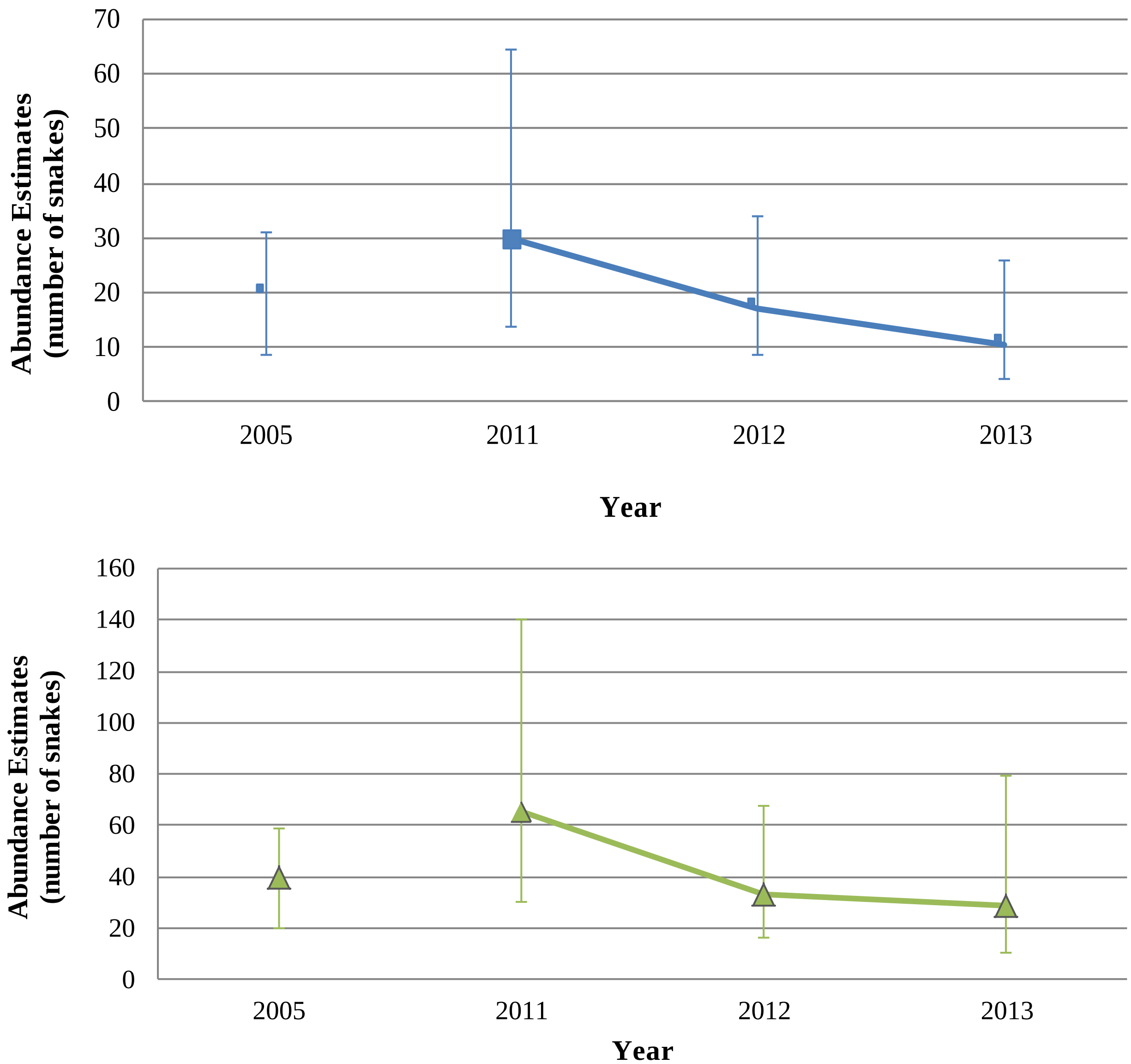


Figure 7. Model-estimated Copperbelly Water Snake total abundance and lower and upper 95% confidence limits (LCL and UCL) based on abundance-induced heterogeneity models (Royle and Nichols 2003) (top graph) and single-season N-mixture repeated count models (Royle 2004) (bottom graph) fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison.

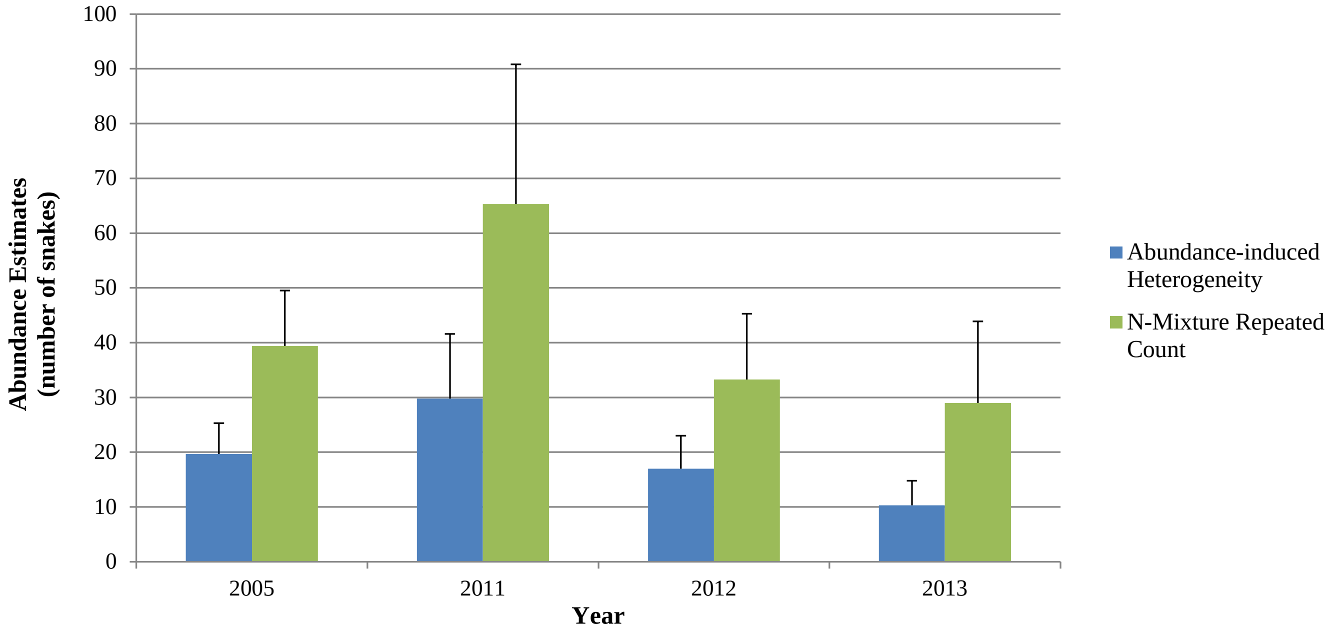


Figure 8. Model-estimated Copperbelly Water Snake total abundance and standard error bars based on abundance-induced heterogeneity models (Royle and Nichols 2003) and single-season N-mixture repeated count models (Royle 2004) fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison. Graph provided for general comparison of abundance estimates across models.

Surveyed Wetlands from Recent Wetland Complexes Only

We used several single-season occupancy models to estimate Copperbelly Water Snake site occupancy and detection probability for just the wetlands that were located in recent wetland complexes (i.e., wetland complexes which have had copperbelly sightings since 2000). This allowed us to examine population parameters and potential trends for just the wetland complexes in which copperbellies have been known to occur most recently, particularly since 13 (81%) of the 16 recent wetland complexes and 67 (59%) of the 113 wetlands surveyed within these complexes were surveyed in all three years. Similar to model results based on data from all wetland complexes surveyed (i.e., recent and unknown wetland complexes), two models, one with constant occupancy and detection probabilities and the second containing abundance-induced heterogeneity in detection probability (Royle and Nichols 2003), were supported by the 2011 and 2013 data (Table 9). However, only one model, the model with variable detection probability among surveys, was supported by the 2012 data (Table 9). The variable detection probability model also seemed to be supported by the 2013 data to some degree (i.e., AIC difference of only 2.34, Table 9).

Single-season occupancy models fit to 2011, 2012, and 2013 data from wetlands surveyed in recent wetland complexes estimated low levels of Copperbelly Water Snake site occupancy and low detection probabilities among these sites (Tables 10, 11, 12 and 13). Additionally, all three single-season models based on detection data generated very similar occupancy estimates and fairly similar detection probability estimates within all three years (Tables 10, 11 and 12). In 2011, naïve occupancy was 0.15, whereas both of the best-approximating models, the constant occupancy and detectability model and the abundance-induced heterogeneity model, estimated occupancy at 0.25 (SE=0.08) and 0.26 (SE=0.09), respectively (Tables 10 and 13). Detection probability was similar for the two best-supported models, with an estimate of 0.32 (SE=0.10) for the constant occupancy and detectability model and 0.28 (SE=0.11) for the abundance-induced heterogeneity model (Tables 10 and 13). In 2012, naïve occupancy was 0.15, as in 2011, and the best-approximating model, the variable detection probability model, estimated occupancy at 0.17 (SE=0.05) (Tables 11 and 13). Detection probability ranged from 0.83 (SE=0.15) for the first survey visit to 0.38 (SE=0.14) for the second survey visit and 0.22 (SE=0.12) for the third survey visit, and averaged 0.48 (SE=0.14) across all three survey visits (Tables 11 and 13). In 2013, naïve occupancy was 0.08, whereas both of the best-approximating models, the constant occupancy and detectability model and the abundance-induced heterogeneity model, estimated occupancy at 0.12 (SE=0.05) (Tables 12 and 13). Detection probability was similar for these two models, with an estimate of 0.37 (SE=0.15) for the constant occupancy and detectability model and 0.35 (SE=0.15) for the abundance-induced heterogeneity model (Tables 12 and 13).

The repeated-count models (Royle 2004) fit to copperbelly count data from wetlands surveyed in recent wetland complexes produced greater occupancy estimates and lower probability of detection than the other single-season models. In 2011, the repeated-count model estimated occupancy at 0.48 (SE=0.14) and detection probability at 0.19 (SE=0.08), whereas the other best-approximating single-season models, the constant occupancy and detectability model and the abundance-induced heterogeneity model, estimated occupancy at 0.25 (SE=0.08) and 0.26 (SE=0.09), and detection probability at 0.32 (SE=0.10) and 0.28 (SE=0.11), respectively (Table

10). In 2012, the repeated-count model estimated occupancy at 0.36 (SE=0.11) and detection probability at 0.25 (SE=0.10), whereas the other best-approximating single-season model, the variable detectability model, estimated occupancy at 0.17 (SE=0.05), and detection probability ranging from 0.22 (SE=0.12) to 0.83 (SE=0.15) and averaging 0.48 (SE=0.14) (Table 11). In 2013, the repeated-count model estimated occupancy at 0.30 (SE=0.13) and detection probability at 0.19 (SE=0.10), whereas the other best-approximating single-season models, the constant occupancy and detectability model and the abundance-induced heterogeneity model, estimated occupancy at 0.12 (SE=0.05) and detection probability at 0.37 (SE=0.15) and 0.35 (SE=0.15), respectively (Table 12).

Abundance estimates based on the Royle and Nichols (2003) and Royle (2004) models and survey data only from wetlands in recent wetland complexes were low, with the Royle (2004) model (i.e., the repeated-count model) producing greater abundance estimates than the Royle and Nichols (2003) model (i.e., abundance-induced heterogeneity model) (Tables 10, 11, 12 and 14). In 2011, total copperbelly abundance for the sites surveyed in recent wetland complexes was estimated at 31.1 (SE=13.0) by the abundance-induced heterogeneity model and 67.5 (SE=27.9) by the repeated-count model (Table 10). In 2012, total abundance for the sites surveyed in recent wetland complexes was estimated at 17.9 (SE=6.6) by the abundance-induced heterogeneity model and 35.1 (SE=13.5) by the repeated-count model (Table 11). In 2013, total abundance for the sites surveyed within recent wetland complexes was estimated at 10.4 (SE=5.0) by the abundance-induced heterogeneity model and 29.4 (SE=15.7) by the repeated-count model (Table 12). Using the abundance-induced heterogeneity model, we estimated average Copperbelly Water Snake abundance at 0.30 (SE=0.13), 0.23 (SE=0.08), and 0.13 (SE=0.06) snakes per site in 2011, 2012, and 2013, respectively. Using the repeated-count model, we estimated average Copperbelly Water Snake abundance at 0.66 (SE=0.27), 0.45 (SE=0.17), and 0.35 (SE=0.19) snakes per site in 2011, 2012, and 2013, respectively.

Table 9. Summary of single-season models used to estimate occupancy (Ψ) and detection probability (*p*) based on Copperbelly Water Snake detection-nondetection data only from wetlands surveyed in recent wetland complexes in Michigan, Ohio, and Indiana in 2011, 2012 and 2013.

Model	ΔAIC	AIC Weight	No. Parameters
2011 (n=102)[1]			
Ψ (.), *p* (.)	0.00	0.4842	2
Ψ (.), *p* (abundance-induced heterogeneity)[2]	0.22	0.4338	2
Ψ (.), *p* (survey-specific)	3.55	0.0821	4
2012 (n=78)[1]			
Ψ (.), *p* (survey-specific)	0.00	0.8918	4
Ψ (.), *p* (.)	5.60	0.0542	2
Ψ (.), *p* (abundance-induced heterogeneity)[2]	5.61	0.054	2
2013 (n=83)[1]			
Ψ (.), *p* (.)	0.00	0.4347	2
Ψ (.), *p* (abundance-induced heterogeneity)[2]	0.02	0.4304	2
Ψ (.), *p* (survey-specific)	2.34	0.1349	4

[1]Sample sizes only include wetlands with suitable copperbelly habitat in recent wetland complexes that were surveyed 1-3 times in 2011, 2012, and 2013.
[2]Royle and Nichols (2003) estimator.

Table 10. 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 survey data only from wetlands surveyed in recent wetland complexes in Michigan, Ohio, and Indiana in 2011 (n=102)[1] (in order of AIC difference for first 3 models).

2011	Occupancy					Detection Probability				Total Abundance			
Model	Naïve	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	*N*	SE	LCL	UCL
Single-season Occupancy - constant *p*[2]	0.15	0.25	0.08	0.13	0.44	0.32	0.10	0.16	0.54	NA[3]	NA	NA	NA
Abundance-induced Heterogeneity[4]	0.15	0.26	0.09	0.13	0.50	0.28	0.11	0.07	0.49	31.1	13.0	13.7	70.6
Single-season Occupancy - variable *p*[5]	0.15	0.25	0.08	0.13	0.44	*p1*-0.36, *p2*-0.34, *p3*-0.27, *(0.32)*	0.14, 0.13, 0.12, *(0.13)*	0.15, 0.14, 0.11, *(0.13)*	0.66, 0.62, 0.54, *(0.61)*	NA[3]	NA	NA	NA
N-Mixture Repeated Count[5]	0.15	0.48	0.14	0.25	0.77	0.19	0.08	0.04	0.34	67.5	27.9	30.0	151.88

[1]Sample size only includes wetlands with suitable copperbelly habitat in recent wetland complexes that were surveyed 1-3 times in 2011, and does not include wetlands that were surveyed in 2012 and/or 2013 but not in 2011.

[2]MacKenzie et al. (2002) model with best supported model having detection probability constant across surveys.

[3]Parameter is not estimated by the model.

[4]Royle and Nichols (2003) estimator.

[5]MacKenzie et al. (2002) model with variable detection probability among surveys – *p1* for survey visit 1, *p2* for survey visit 2, *p3* for survey visit 3, and average values in parentheses and italics. Model results provided for comparison but model was not well-supported by the data because AIC difference was greater than 2.

[6]Royle (2004) model.

Table 11. 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 survey data only from wetlands surveyed in recent wetland complexes in Michigan, Ohio, and Indiana in 2012 (n=78)[1] (in order of AIC difference for first 3 models).

2012	Occupancy					Detection Probability				Total Abundance			
Model	Naïve	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	*N*	SE	LCL	UCL
Single-season Occupancy - variable *p*[2]	0.15	0.17	0.05	0.10	0.29	*p*1 - 0.83, *p*2 – 0.38, *p*3 – 0.22, *(0.48)*	0.15, 0.14, 0.12, *(0.14)*	0.36, 0.16, 0.07, *(0.20)*	0.98, 0.66, 0.52, *(0.72)*	NA[3]	NA	NA	NA
Single-season Occupancy - constant *p*[4]	0.15	0.20	0.06	0.10	0.35	0.40	0.11	0.21	0.62	NA[3]	NA	NA	NA
Abundance-induced Heterogeneity[5]	0.15	0.20	0.07	0.11	0.38	0.36	0.12	0.13	0.59	17.9	6.6	8.7	37.7
N-Mixture Repeated Count[6]	0.15	0.36	0.11	0.19	0.62	0.25	0.10	0.06	0.43	35.1	13.5	16.5	74.7

[1]Sample size only includes wetlands with suitable copperbelly habitat in recent wetland complexes that were surveyed 1-3 times in 2012, and does not include wetlands that were surveyed in 2011 and/or 2013 but not in 2012.

[2]MacKenzie et al. (2002) model with best supported model having variable detection probability among surveys – *p1* for survey visit 1, *p2* for survey visit 2, *p3* for survey visit 3, and average values in parentheses and italics.

[3]Parameter is not estimated by the model.

[4]MacKenzie et al. (2002) model with detection probability constant across surveys. Model results provided for comparison but model was not well-supported by the data because AIC difference was greater than 2.

[5]Royle and Nichols (2003) estimator. Model results provided for comparison but model was not well-supported by the data because AIC difference was greater than 2.

[6]Royle (2004) model.

Table 12. 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 survey data only from wetlands surveyed in recent wetland complexes in Michigan, Ohio, and Indiana in 2013 (n=83)[1] (in order of AIC difference for first 3 models).

2013	Occupancy					Detection Probability				Total Abundance			
Model	Naïve	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	*N*	SE	LCL	UCL
Single-season Occupancy - constant *p*[2]	0.08	0.12	0.05	0.05	0.26	0.37	0.15	0.14	0.67	NA[3]	NA	NA	NA
Abundance-induced Heterogeneity[4]	0.08	0.12	0.05	0.05	0.27	0.35	0.15	0.12	0.67	10.4	5.0	4.1	26.6
Single-season Occupancy - variable *p*[5]	0.08	0.11	0.05	0.05	0.24	*p1*-0.51, *p2*-0.44, *p3*-0.22, *(0.39)*	0.24, 0.21, 0.15, *(0.20)*	0.14, 0.13, 0.05, *(0.11)*	0.87, 0.80, 0.62, *(0.76)*	NA[3]	NA	NA	NA
N-Mixture Repeated Count[6]	0.08	0.30	0.13	0.12	0.63	0.19	0.10	-0.01	0.39	29.4	15.7	10.3	83.6

[1]Sample size only includes wetlands with suitable copperbelly habitat in recent wetland complexes that were surveyed 1-3 times in 2013, and does not include wetlands that were surveyed in 2011 and/or 2012 but not in 2013.

[2]MacKenzie et al. (2002) model with best supported model having detection probability constant across surveys.

[3]Parameter is not estimated by the model.

[4]Royle and Nichols (2003) estimator.

[5]MacKenzie et al. (2002) model with variable detection probability among surveys – *p1* for survey visit 1, *p2* for survey visit 2, *p3* for survey visit 3, and average values in parentheses and italics. Model results provided for comparison but model was not well-supported by the data because AIC difference was greater than 2.

[6]Royle (2004) model.

Table 13. 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 data only from wetlands surveyed in recent wetland complexes in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison.

	Occupancy					Detection Probability				Total Abundance			
Models	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
2011 (n=102)													
Single-season Occupancy[1]	0.15	0.25	0.08	0.13	0.44	0.32	0.10	0.16	0.54	NA[2]	NA	NA	NA
Abundance-induced Heterogeneity[3]	0.15	0.26	0.09	0.13	0.50	0.28	0.11	0.07	0.49	31.1	13.0	13.7	70.6
2012 (n=78)													
Single-season Occupancy[4]	0.15	0.17	0.05	0.10	0.29	*p1*-0.83, *p2*-0.38, *p3*-0.22, *(0.48)*	0.15, 0.14, 0.12, *(0.14)*	0.36, 0.16, 0.07, *(0.20)*	0.98, 0.66, 0.52, *(0.72)*	NA[2]	NA	NA	NA
Abundance-induced Heterogeneity[3, 5]	0.15	0.20	0.07	0.11	0.38	0.36	0.12	0.13	0.59	17.9	6.6	8.7	36.7
2013 (n=83)													
Single-season Occupancy[1]	0.08	0.12	0.05	0.05	0.26	0.37	0.15	0.14	0.67	NA[2]	NA	NA	NA
Abundance-induced Heterogeneity[3]	0.08	0.12	0.05	0.05	0.27	0.35	0.15	0.12	0.67	10.4	5.0	4.1	26.6

[1]MacKenzie et al. (2002) model, with best supported model having detection probability constant across surveys.
[2]Parameter is not estimated by the model.
[3]Royle and Nichols (2003) estimator.
[4]MacKenzie et al. (2002) model, with best supported model having variable detection probability among surveys. Detection probability, SE, LCL, and UCL estimates for survey visit 1 (*p1*), 2 (*p2*), and 3 (*p3*) and average values (in parentheses and italics) are provided.
[5]Model was not best supported by the data in 2012, but results are provided for comparison.

Table 14. 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 N-mixture repeated count models (Royle 2004) fit to data only from wetlands surveyed in recent wetland complexes in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Results from 2005 are included for comparison.

	Occupancy					Detection Probability				Total Abundance			
Model[1]	Naïve	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL	*N*	SE	LCL	UCL
2005 (n=105)	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
2011 (n=102)	0.15	0.48	0.14	0.25	0.77	0.19	0.08	0.04	0.34	67.5	27.9	30.0	151.9
2012 (n=78)	0.15	0.36	0.11	0.19	0.62	0.25	0.10	0.06	0.43	35.1	13.5	16.5	74.7
2013 (n=83)	0.08	0.30	0.13	0.12	0.63	0.19	0.10	-0.01	0.39	29.4	15.7	10.3	83.6

[1]Results for Royle (2004) model only.

Multiple-season Models

Surveyed Wetlands from Recent and Unknown Wetland Complexes

We found the multi-season model with variable occupancy among seasons (or years) and constant detection probability to be the best-approximating model of those examined (Table 15). The model with constant occupancy and detection probability was the second best-approximating model (Table 15). The other two multi-season models, one with variable occupancy and detection probability among seasons/years and the other with variable occupancy among seasons/years and variable detection probability among individual surveys, had AIC differences greater than two, indicating these models not supported by the data (Burnham and Anderson 2002) (Table 15).

Similar to the single-season models, the multi-season models also produced low estimates of occupancy, detection probability, colonization probability, and extinction probability. Of the 105 sites/wetlands that were surveyed during multiple years and available for multi-year analysis, Copperbelly Water Snakes were observed during at least one survey in 0.14 of the sites in 2011, 0.11 of the sites in 2012, and 0.07 of the sites in 2013. The model best supported by the data with variable occupancy among seasons/years and constant detectability provided occupancy estimates of 0.15 (SE=0.04) for 2011, 0.12 (SE=0.03) for 2012, and 0.07 (SE=0.03) for 2013, whereas the second best-approximating model with constant occupancy and detectability estimated occupancy at 0.11 (SE=0.03) for all three years (Table 16, Figure 9). Both models produced a detection probability estimate of 0.34 (SE=0.06) for all three years (Table 16, Figure 10). The model best supported by the data with variable occupancy among seasons and constant detectability estimated the probability of colonization at 0.01 (SE=0.01) for 2011-2012 and 2012-2013, and extinction probability at 0.26 (SE=0.18) for 2011-2012 and 0.48 (SE=0.19) for 2012-2013 (Table 16). The second-best approximating model with constant occupancy and detection probability estimated the probability of colonization at 0.03 (SE=0.02) and extinction probability at 0.25 (SE=0.13) for both 2011 and 2012 (Table 16).

Table 15. Summary of multi-season models used to estimate Copperbelly Water Snake occupancy (Ψ) and probabilities of detection (*p*), extinction (ε), and colonization (γ) during surveys in 2011, 2012, and 2013 at all wetlands surveyed in Michigan, Ohio and Indiana.

Model[1]	ΔAIC	AIC Weight	No. Parameters
Ψ (season), γ, ε, *p* (.)	0.00	0.4976	5
Ψ (.), γ, ε, *p* (.)	0.39	0.4094	3
Ψ (season), γ, ε, *p* (season)	3.94	0.0694	7
Ψ (season), γ, ε, *p* (survey-specific)	6.10	0.0236	13

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

Table 16. Observed and model-estimated Copperbelly Water Snake occupancy (Ψ) and probabilities of detection (*p*), extinction (ε), and colonization (γ) based on best multi-season models supported by data from surveys conducted in 2011, 2012, and 2013 at all wetlands surveyed in Michigan, Ohio and Indiana.

	Occupancy					Detection Probability			
	Obs.[2]	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL
Model: Ψ (season), γ, ε, *p* (.)[1]									
2011	0.10	0.15	0.04	0.09	0.25	0.34	0.06	0.23	0.46
2012	0.10	0.12	0.03	0.07	0.20	0.34	0.06	0.23	0.46
2013	0.10	0.07	0.03	0.03	0.14	0.34	0.06	0.23	0.46
Model: Ψ (.), γ, ε, *p* (.)[1]									
2011	0.10	0.11	0.03	0.07	0.18	0.34	0.06	0.23	0.47
2012	0.10	0.11	0.03	0.07	0.18	0.34	0.06	0.23	0.47
2013	0.10	0.11	0.03	0.07	0.18	0.34	0.06	0.23	0.47
Model Average	*0.10*	*0.11*	*0.03*	*0.07*	*0.19*	*0.34*	*0.06*	*0.23*	*0.47*

	Colonization Probability				Extinction Probability			
	γ	SE	LCL	UCL	ε	SE	LCL	UCL
Model: Ψ (season), γ, ε, *p* (.)[1]								
2011 - 2012	0.01	0.01	0.0004	0.17	0.26	0.18	-0.09	0.61
2012 - 2013	0.01	0.01	0.0004	0.17	0.48	0.19	0.10	0.85
Model: Ψ (.), γ, ε, *p* (.)[1]								
2011 - 2012	0.03	0.02	0.01	0.08	0.25	0.13	-0.01	0.50
2012 - 2013	0.03	0.02	0.01	0.08	0.25	0.13	-0.01	0.50
Model Average								
2011-2012	*0.02*	*0.02*	*0.01*	*0.13*	*0.26*	*0.16*	*-0.05*	*0.56*
2012-2013	*0.02*	*0.02*	*0.01*	*0.13*	*0.37*	*0.16*	*0.05*	*0.68*

[1]MacKenzie et al. (2003) multi-season occupancy model – two models best supported by the data.
[2]Observed or naïve occupancy.

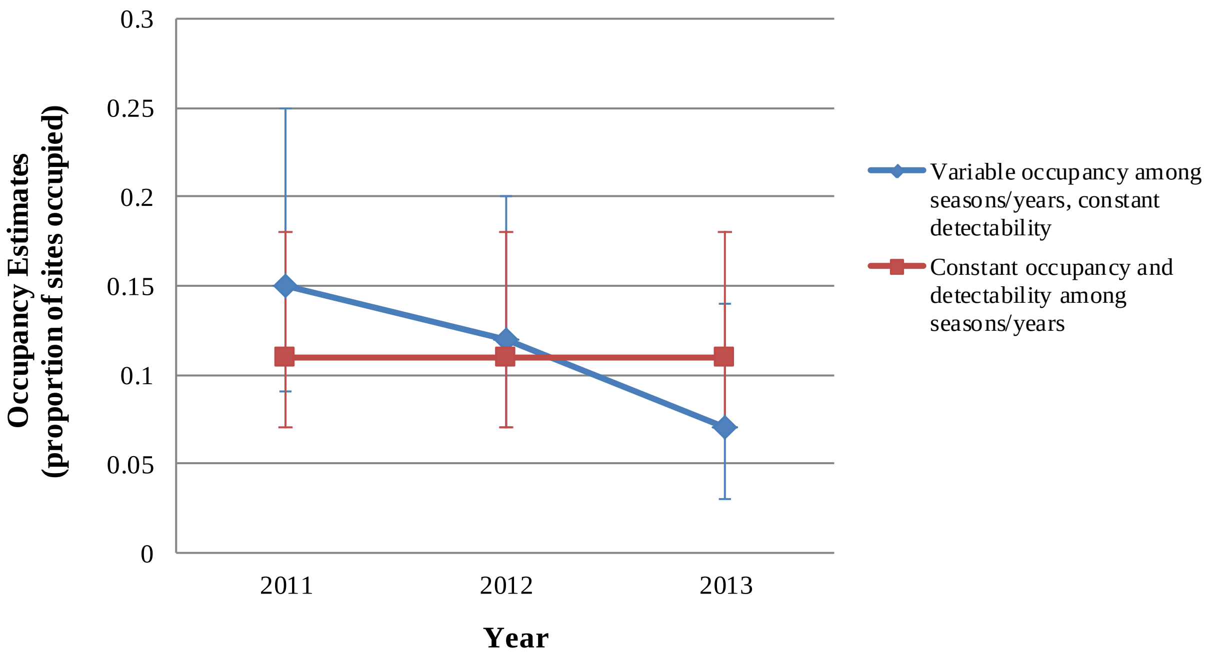


Figure 9. Model-estimated occupancy of Copperbelly Water Snakes based on best-supported/ best-approximating multi-season model (MacKenzie et al. 2003) with variable occupancy and constant detectability among seasons/years, and second best-approximating multi-season model (MacKenzie et al. 2003) with constant occupancy and detectability among seasons/years fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Graph provided for general comparison of occupancy estimates across years and models.

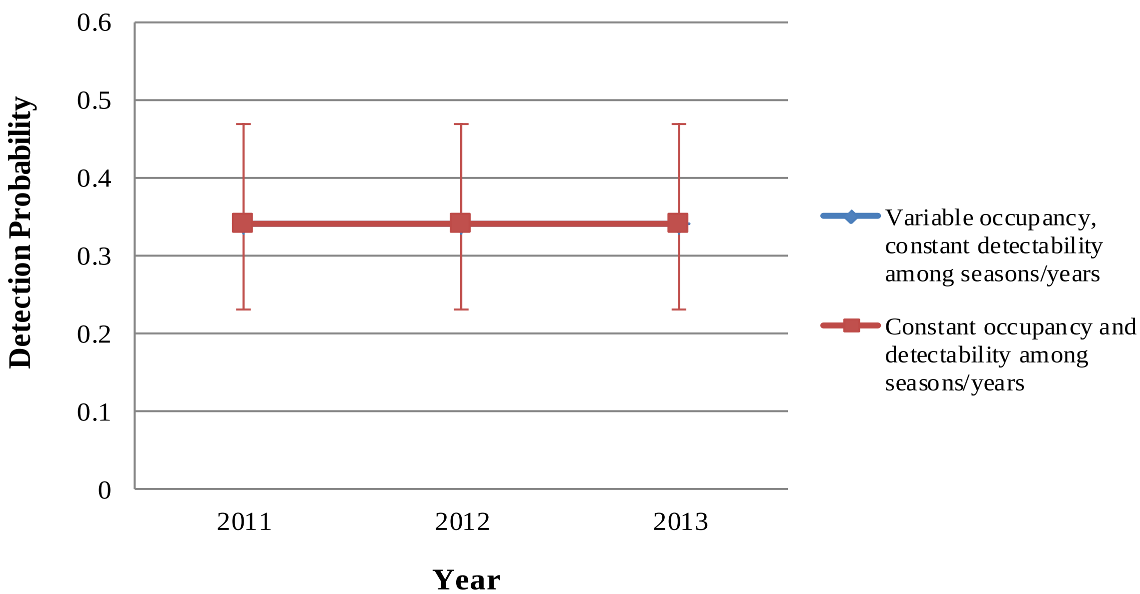


Figure 10. Model-estimated detection probability of Copperbelly Water Snakes based on best-supported/best-approximating multi-season model (MacKenzie et al. 2003) with variable occupancy and constant detectability among seasons/years, and second best-approximating multi-season model with constant occupancy and detectability among seasons/years fit to survey data from all wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Graph provided for general comparison of detection probability estimates across years and models.

Surveyed Wetlands from Recent Wetland Complexes Only

The multi-season model results based on just the sites or wetlands surveyed in recent wetland complexes were similar but slightly different than the multi-season model results based on all wetlands surveyed. Both the multi-season model with constant occupancy and detection probability and the model with variable occupancy among seasons/years and constant detection probability were again the top two models supported by the data, but the constant occupancy and detection probability model was the best-approximating model in this case (Table 17). The multi-season model with variable occupancy among seasons/years and constant detection probability was the second best-approximating model (Table 17). The other two multi-season models, one with variable occupancy and detectability among seasons and the other with variable occupancy among seasons and variable detectability among individual surveys, had AIC differences greater than two, indicating these models not supported by the data (Burnham and Anderson 2002) (Table 17).

The multi-season models based on just the wetlands surveyed in recent wetland complexes produced low estimates of occupancy, detection probability, colonization probability, and extinction probability. Of the 105 wetlands that were surveyed during multiple years and available for multi-year analysis, 91 of them were located in recent wetland complexes. Of these 91 wetlands, Copperbelly Water Snakes were observed during at least one survey in 0.16 of the sites in 2011, 0.13 of the sites in 2012, and 0.08 of the sites in 2013. The model best supported by the data with constant occupancy and detection probability estimated copperbelly occupancy among wetlands in recent wetland complexes at 0.18 (SE=0.04) for all three years, whereas the second best-approximating model with variable occupancy among seasons/years and constant detectability provided occupancy estimates of 0.23 (SE=0.06) for 2011, 0.19 (SE=0.05) for 2012, and 0.12 (SE=0.04) for 2013 (Table 18). Both models produced a detection probability estimate of 0.34 (SE=0.06) for all three years (Table 18). The model best supported by the data estimated the probability of colonization at 0.04 (SE=0.02) and extinction probability at 0.20 (SE=0.13) for 2011-2012 and 2012-2013 (Table 18). The second-best approximating model estimated the probability of colonization at 0.01 (SE=0.02) for 2011-2012 and 2012-2013, and extinction probability at 0.19 (SE=0.17) for 2011-2012 and 0.44 (SE=0.20) for 2012-2013 (Table 18).

Table 17. Summary of multi-season models used to estimate Copperbelly Water Snake occupancy (Ψ) and probabilities of detection (p), extinction (ε), and colonization (γ) during surveys in 2011, 2012, and 2013 only at wetlands in recent wetland complexes in Michigan, Ohio and Indiana.

Model[1]	ΔAIC	AIC Weight	No. Parameters
Ψ (.), γ, ε, p (.)	0.00	0.4621	3
Ψ (season), γ, ε, p (.)	0.04	0.4530	5
Ψ (season), γ, ε, p (season)	3.99	0.0629	7
Ψ (season), γ, ε, p (survey-specific)	6.09	0.022	13

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

Table 18. Observed and model-estimated Copperbelly Water Snake occupancy (Ψ) and probabilities of detection (*p*), extinction (ε), and colonization (γ) based on multi-season models best supported by data from surveys conducted in 2011, 2012, and 2013 only at wetlands in recent wetland complexes in Michigan, Ohio and Indiana.

	Occupancy					Detection Probability			
	Obs.[2]	Est. Ψ	SE	LCL	UCL	*p*	SE	LCL	UCL
Model: Ψ (.), γ, ε, *p* (.)[1]									
2011	0.18	0.18	0.04	0.11	0.28	0.34	0.06	0.23	0.47
2012	0.18	0.18	0.04	0.11	0.28	0.34	0.06	0.23	0.47
2013	0.18	0.18	0.04	0.11	0.18	0.34	0.06	0.23	0.47
Model: Ψ (season), γ, ε, *p* (.)[1]									
2011	0.18	0.23	0.06	0.14	0.36	0.34	0.06	0.24	0.46
2012	0.18	0.19	0.05	0.11	0.32	0.34	0.06	0.24	0.46
2013	0.18	0.12	0.04	0.06	0.23	0.34	0.06	0.24	0.46
Model Average	*0.18*	*0.18*	*0.05*	*0.11*	*0.29*	*0.34*	*0.06*	*0.24*	*0.47*

	Colonization Probability				Extinction Probability			
	γ	SE	LCL	UCL	ε	SE	LCL	UCL
Model: Ψ (.), γ, ε, *p* (.)[1]								
2011 - 2012	0.04	0.02	0.01	0.12	0.20	0.13	0.05	0.44
2012 - 2013	0.04	0.02	0.01	0.12	0.20	0.13	0.05	0.44
Model: Ψ (season), γ, ε, *p* (.)[1]								
2011 - 2012	0.01	0.02	0.0003	0.34	0.19	0.17	0.13	0.52
2012 - 2013	0.01	0.02	0.0003	0.34	0.44	0.20	0.05	0.82
Model Average								
2011-2012	*0.03*	*0.02*	*0.01*	*0.23*	*0.20*	*0.15*	*0.09*	*0.48*
2012-2013	*0.03*	*0.02*	*0.01*	*0.23*	*0.32*	*0.17*	*0.05*	*0.63*

[1]MacKenzie et al. (2003) multi-season occupancy model – two models best supported by the data.
[2]Observed or naïve occupancy.

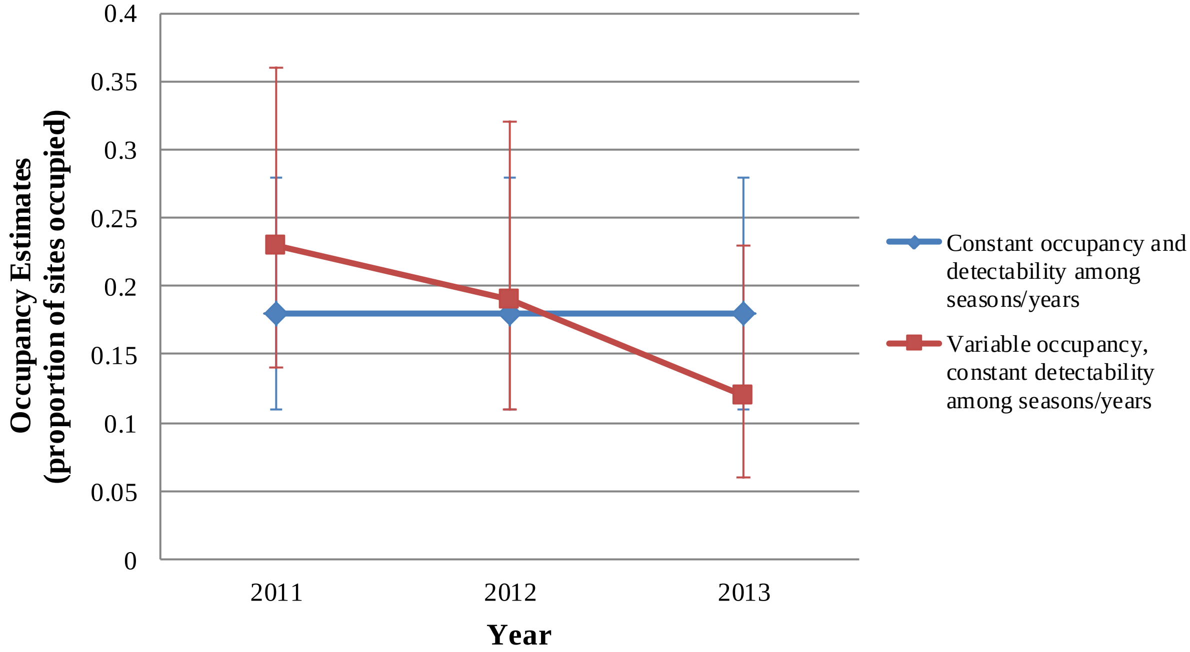


Figure 11. Model-estimated occupancy of Copperbelly Water Snakes based on best-supported/ best-approximating multi-season model (MacKenzie et al. 2003) with constant occupancy and detectability among seasons/years, and second best-approximating multi-season model with variable occupancy and constant detectability among seasons/years fit to survey data from only recent wetlands surveyed in Michigan, Ohio, and Indiana in 2011, 2012, and 2013. Graph provided for general comparison of occupancy estimates across years and models.

DISCUSSION

Surveys

The number of Copperbelly Water Snake observations and the number of wetland complexes and wetlands in which copperbellies were documented during surveys in 2012 and 2013 remained very low. Additionally, the number of copperbelly observations and the number of wetland complexes and wetlands in which copperbellies were documented were lower in 2013 than in 2011 and 2012. Surveys in 2012 documented a slightly lower but similar number of copperbelly observations in a similar number of wetlands and wetland complexes as in 2011, with 25 observations in 12 different wetlands in 7 wetland complexes in 2012 compared to 32 observations in 15 different wetlands in 7 wetland complexes in 2011. These results are similar to survey results obtained in 2005, with 38 copperbelly observations in 15 different wetlands. However, only 16 copperbelly observations were documented in only 7 different wetlands in 4 wetland complexes in 2013, which is about 40-50% fewer copperbelly observations and fewer wetlands/wetland complexes in which copperbellies were observed than what was documented in 2011 and 2012.

There are several factors that may have contributed to fewer copperbelly observations in fewer wetlands/wetland complexes documented during surveys in 2013 than in 2012 and 2011. Lack of landowner permission or access to several wetlands that were part of two recent wetland complexes at which copperbellies have been documented may have contributed to fewer copperbelly observations and a smaller number of wetlands in which copperbellies were documented in 2013. In addition, copperbellies were not observed at three wetlands in three different wetland complexes in 2013 at which copperbellies had been regularly observed during surveys in 2011 and 2012. The drought conditions we had during the spring and summer of 2012 which resulted in a number of wetlands that were surveyed as part of the monitoring program drying up completely and/or earlier than normal also may have contributed to fewer copperbelly observations in 2013. This may have resulted in reduced availability of prey for copperbellies in 2012 since they feed primarily on adult frogs and tadpoles, particularly in shallow, temporary wetlands in the spring, which, in turn, may have impacted the copperbelly population later in the year in 2012 and/or in 2013. Sellers (pers. comm.) has suggested that drought conditions can significantly impact copperbelly populations and habitat. Additionally, some tree/shrub removal and small-scale timber harvesting occurred in and around several wetlands at which copperbellies had been observed during earlier surveys, which may have impacted copperbelly habitat suitability and potentially occurrence at these sites.

In comparison to the low numbers of Copperbelly Water Snakes that were documented during the monitoring surveys in 2012 and 2013, the numbers of Northern Water Snakes that were observed during those surveys were much higher than the numbers of Copperbelly Water Snakes that were observed. Over 4-5 times as many Northern Water Snake observations were documented in 2012 and 2013, respectively. Additionally, Northern Water Snakes were observed in almost 3-5 times the number of wetlands in which copperbellies were observed in 2012 and 2013, respectively. Fewer Northern Water Snake observations were documented in 2013 than in 2012 (about 20% fewer), but the number of wetlands and wetland complexes in which they were observed remained essentially the same or a little higher in 2013 than in 2012.

Copperbelly Water Snakes were documented in the same wetland complexes and some of the same wetlands during surveys in 2011-2013 as well as in 2005 and/or 2006. Copperbelly Water Snakes were documented in the same seven wetland complexes in 2012 and 2013 as in 2011 (i.e., G5696, G5708, G5933, G4865, G4868, G5849, and G5837). These complexes also were occupied by copperbellies in 2005 and 2006. Of the 20 wetlands in which copperbellies have been documented during surveys in 2011-2013, copperbellies were documented in 10 of these wetlands during two or all three years of the monitoring surveys. Of the remaining 10 wetlands, copperbellies were documented in 5 wetlands in 2012 and/or 2013 but not in 2011, and in the other 5 wetlands in 2011 but not in 2012 and/or 2013. 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 likely contributed to similar numbers and/or locations of copperbelly observations documented in 2012 and 2013 as in 2011 as well as 2005. However, copperbellies also were documented in some different or new wetlands in 2012 and/or 2013 compared to those in 2011 and/or 2005.

Population Parameter Estimates

Single-season Models

The 2012 and 2013 single-season occupancy model results (i.e., fit to data from all wetland complexes/ wetlands surveyed and from recent wetland complexes/wetlands only) differed slightly between the two years and from the 2011 and 2005 single-season occupancy model results. The 2013 single-season model results were similar to the 2011 and 2005 single-season model results in that the constant occupancy and detection probability model and the abundance-induced heterogeneity model ranked the highest and were best-supported by the data in 2013 and in 2011 and 2005. However, the 2012 single-season model results were different in that the variable detection probability among surveys model ranked the highest and was best supported by the data in 2012. This model generated a significantly higher detection probability for the first survey visit or window (i.e., 0.83) compared to the detection probabilities for the second and third survey visits/windows (i.e., 0.38 and 0.22, respectively) (Tables 5 and 11, Figure 4). This was likely due to drought conditions in 2012 which resulted in a number of surveyed wetlands drying up earlier than normal by the second and/or third survey visit. There also seemed to be some support for the variable detection probability model with the 2013 data (i.e., ΔAIC only slightly greater than 2) (Tables 3 and 9). This model generated higher detection probabilities for the first two survey visits/windows (i.e., 0.50/0.51 and 0.44) compared to that for the third survey visit (0.22) (Tables 6 and 12). The variable detection probability model based on the 2011 data also generated a similar trend in detection probability (i.e., decreasing detection from the first to the third survey visit/window), but the detection probability estimates were fairly similar across the survey visits (i.e., 0.37, 0.33, and 0.26) (Table 4). It is important to note though that all three of the single-season models generated very similar occupancy estimates and somewhat similar detection probability estimates within each of the three years.

The repeated-count single-season models (Royle 2004) based on data from 2012 and 2013 consistently generated higher occupancy estimates and lower detection probability estimates than the other three single-season models within both years (Tables 5 and 6). Repeated-count models based on data from 2011 and 2005 also generated similar results (Table 4, Lee et al. 2011). Because the repeated-count model is a different type or class of occupancy model and is focused primarily on generating abundance estimates, it may be more reliable to use the occupancy and detection probability estimates generated from the other single-season models (i.e., constant occupancy and detection probability, variable detection probability among surveys, and abundance-induced heterogeneity models) than those generated from the repeated-count model. However, these estimates could be used in conjunction with estimates from other models to detect population trends over time.

Based on data from all wetland complexes/wetlands surveyed, observed (naïve) and estimated occupancy in 2012 were fairly consistent with the observed and estimated occupancy generated from the 2011 data. Estimated occupancy in 2012 was slightly lower than estimated occupancy in 2011 (i.e., 0.12 - 0.14 in 2012, 0.19 - 0.20 in 2011), but these estimates were not significantly different based on the standard errors and 95% confidence intervals. Observed and estimated occupancy in 2011 and 2012 were fairly consistent with observed and estimated occupancy generated from the 2005 data (Table 7). Observed and estimated occupancy in 2013 were lower than observed and estimated occupancy in 2005, 2011, and 2012, but occupancy estimates were not significantly different based on the standard errors and 95% confidence intervals. Observed and estimated occupancy for 2011, 2012, and 2013 based on only recent wetland complexes/wetlands surveyed were slightly higher than occupancy estimates for all wetland complexes/wetlands surveyed but indicated the same general trends with slightly lower observed and/or estimated occupancy in 2012 and 2013 compared to occupancy in 2011 and/or 2005. But again occupancy estimates were not significantly different across all three years based on the standard errors and 95% confluence intervals. As mentioned earlier, copperbelly occupancy may have been lower in 2013 because of drought conditions in 2012 and/or lack of surveys at several wetlands at which copperbellies had been regularly documented. Additionally, more unknown/historical wetland complexes and wetlands were surveyed in 2013 than in 2011 and 2012. Since no copperbellies have been documented in unknown/historical wetland complexes/wetlands, this may have resulted in lower occupancy estimates (i.e., proportion of wetlands occupied). More data or years of monitoring are needed to better assess trends in copperbelly occupancy within the study area. These results do indicate, though, that copperbelly occupancy, in terms of proportion of wetlands occupied, remains very low (i.e., $\leq$0.20).

Total copperbelly abundance estimates were lower based on the 2012 and 2013 survey data than those based on the 2011 data. Based on data from all wetland complexes/wetlands surveyed, the abundance-induced heterogeneity model generated total abundance estimates of 17.0 (SE=6.0) in 2012 and 10.3 (SE=4.5) in 2013 compared to 29.8 (SE=11.8) in 2011 (Table 7). Similarly, the repeated-count model generated total abundance estimates of 33.3 (SE=12.0) in 2012 and 29.0 (SE=14.9) in 2013 compared to 65.3 (SE=25.5) in 2011 (Table 8). Similar abundance estimates were generated from these models with data from only recent wetland complexes/wetlands that were surveyed (Tables 13 and 14). But the standard errors and confidence intervals for abundance estimates in 2012 and 2013 overlapped quite a bit with those for the abundance estimates in 2011 (Figures 7 and 8), indicating they are likely not significantly different. Additionally, total copperbelly abundance estimates for 2012 and 2013 were slightly lower but quite similar to abundance estimates generated from the 2005 data (Figures 7 and 8). Because the total abundance estimate is derived by multiplying the average abundance estimate by the total number of sample sites, different sample sizes (i.e., number of wetlands surveyed and included in the analysis/abundance calculation) could have impacted total abundance estimates.

The largest sample size or number of wetlands surveyed was in 2011 compared to the other years. However, more wetlands were surveyed in 2013 (n=124) than in 2012 (n=110) but the total abundance estimates for 2013 were lower than those for 2012. 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, and can be used to help detect and monitor trends in the population. However, more data or years of monitoring are needed to assess or determine trends in copperbelly abundance over time within the study area. As a side note, total abundance estimates generated by occupancy models with data from 2005, 2011, 2012, and 2013 were lower than the estimated total adult Copperbelly Water Snake population size (N=94 $\pm$ 22) generated using distance sampling and survey data from 34 wetlands in 2006 (Attum et al. 2009).

Detection probability estimates generated from the 2011, 2012 and 2013 single-season models, particularly the constant occupancy and detectability and the abundance-induced heterogeneity models, were fairly consistent, and were generally lower than the detection probability estimates generated from the 2005 survey data. The detection probability estimates generated from the constant occupancy and detectability model and the abundance-induced heterogeneity model based on data from all wetlands surveyed ranged from 0.29 - 0.32 in 2011, 0.37 – 0.40 in 2012, and 0.35 - 0.36 in 2013 (Tables 4, 5 and 6; Figures 4 and 6). Detection probability estimates generated from the variable detection probability models had larger ranges, ranging from 0.26 – 0.37 in 2011, 0.23 - 0.83 in 2012, and 0.22 - 0.50 in 2013, but the average detection probability estimates across the three survey visits were comparable across the three years (i.e., 0.32 in 2011, 0.48 in 2012 and 0.39 in 2013) (Tables 4, 5 and 6; Figures 4 and 6). The detection probability estimates from the repeated-count models for 2011, 2012 and 2013 were even lower, ranging from 0.19 to 0.26 (Table 8, Figures 5 and 6). Detection probability estimates from all the 2011-2013 single-season models were generally lower than those generated from the 2005 single-season models, which ranged from 0.40 to 0.58 (Monfils and Lee 2011). The lower detection probability estimates in 2011, 2012, and 2013 may have been due to the addition of historical or unknown copperbelly sites to the surveys whereas surveys in 2005 focused only on known or recent copperbelly sites. Also, in 2005, more than 3 survey visits (i.e., 4 or 5 visits) were conducted at some wetlands to confirm copperbelly presence, which may have resulted in higher detection probability. 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, 2012, and 2013. 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.

Multiple-season Models

The multiple- or multi-season model results based on data from 2011, 2012, and 2013 were similar to results of the multi-season models that included data from 2005 and 2006 and multi-season models that included data from 2005, 2006, and 2011 (Monfils and Lee 2011, Lee et al. 2011). Based on data from all wetland complexes/wetlands and only from recent wetland complexes/wetlands surveyed in 2011-2013, the multi-season model with variable occupancy among seasons (years) and constant detection probability and the model with constant occupancy and detection probability were the best- and second best-approximating models, respectively, of those examined (Table 15). These two multi-season models also were best supported by the

2005-2006 data, although the model with constant occupancy and detection probability was the best-approximating model and the model with variable occupancy among seasons and constant detectability was the second best-approximating model (Monfils and Lee 2011). With data from 2005-2006 and 2011, only the multi-season model with constant occupancy and detectability was supported by the data (Lee et al. 2011). Consistency in model results across multiple years indicate that these two models (i.e., constant occupancy and detectability and variable occupancy among seasons/years and constant detectability) seem to be best supported by the copperbelly monitoring data, and that the other two multi-season models, one with variable occupancy and detectability among seasons and the other with variable occupancy among seasons and variable detectability among individual surveys, are not well-supported by the data. These results also suggest that occupancy may have differed across years but detection probability appears to have remained constant across multiple years.

The multi-season models with data from 2011-2013 generated fairly similar or slightly lower occupancy and detection probability estimates than those generated from single-season models. The multi-season model with variable occupancy among seasons (years) and constant detectability estimated occupancy of 0.15 (SE=0.04) for 2011; 0.12 (SE=0.03) for 2012; and 0.07 (SE=0.03) for 2013 (Table 17, Figure 9). The single-season models estimated occupancy of 0.19 -0.20 (SE=0.06-0.07) for 2011; 0.12 - 0.14 (SE=0.03-0.05) for 2012; and 0.08 (SE=0.04) for 2013 (Table 7, Figures 1 and 3). The multi-season models for 2011-2013 generated detection probability estimates of 0.34 for all three years (Table 17, Figure 10). The single-season models generated detection probability estimates of 0.29 – 0.32 (SE=0.10 - 0.11) for 2011; 0.37 – 0.48 average detection probability (average SE=0.12 - 0.14) for 2012; and 0.35 – 0.36 (SE=0.15) for 2013 (Table 7, Figure 4). Similar multi-season and single-season model results provide some corroboration of occupancy and detection probability estimates or results, such as a potential decreasing trend in occupancy from 2011-2013. As with the single-season model results, more data are needed to assess and evaluate trends in occupancy using multi-season models.

Multi-season models with data from 2011-2013 generated slightly lower occupancy and detection probability estimates than estimates generated from the multi-season models with data from only 2005-2006 and with 2011 data, although these estimates may not be significantly different based on the standard errors and 95% confidence intervals. The best-approximating multi-season models with data from 2011-2013 generated occupancy estimates that ranged from 0.07 – 0.15 (SE=0.03-0.04), and a detection probability estimate of 0.34 (SE=0.06) (Table 16). The best-approximating multi-season models with data from 2005-2006 generated occupancy estimates of 0.19 (SE=0.08) in 2005 to 0.25 (SE=0.10) in 2006, and a detection probability estimate of 0.59 (SE=0.13) (Monfils and Lee 2011). The best-approximating multi-season model with data from 2005-2006 and 2011 generated an occupancy estimate of 0.30 (SE=0.08) and a detection probability of 0.44 (SE=0.10) (Lee et al. 2011). These results suggest a potential decreasing trend in occupancy from 2005, 2006, and/or 2011 to 2012 and 2013, but more data are needed to further assess trends in occupancy over time.

The colonization probability estimates for the multi-season models with data from 2011-2013 (γ=0.01-0.03, SE=0.01-0.02) were very low, and much lower than the extinction probability estimates from 2011-2013 data (ε=0.25-0.48, SE=0.13-0.19). These estimates were based on data from all wetlands surveyed including wetlands that were part of unknown or historical wetland complexes that were surveyed during only one of the three years. However, similar results were obtained (i.e., γ=0.01-0.04, SE=0.02; ε=0.19-0.44, SE=0.17-0.120) when the analysis only included data from wetlands that were part of recent wetland complexes, of which ~70% of the wetlands were surveyed during two or three years of the three-year monitoring period. These estimates indicate and seem to corroborate our findings that there was relatively little change in copperbelly site occupancy across the three-year monitoring period, and the higher extinction probability than colonization probability suggests the potential for a decreasing trend over time. Although the extinction probability was higher from 2012-2013 than from 2011-2012, these estimates were not significantly different based on the standard errors and 95% confidence intervals. The 2011-2013 colonization probability estimates were much lower than those generated from the multi-season models with data from 2005-2006 (γ=0.17–0.21, SE=0.08–0.11) (Monfils and Lee 2011) and with data from 2005-2006 and 2011 (γ=0.24, SE=0.10) (Lee et al. 2011). The 2011-2013 extinction probability estimates also were lower than those generated by multi-season models with data from 2005-2006 (ε=0.57-0.62, SE=0.21-0.26) (Monfils and Lee 2011) and 2005-2006 and 2011 (ε=0.57, SE=0.19) (Lee et al. 2011). However, because differences in study designs and observers' abilities to detect the target species can impact and bias parameter estimates with these models, the colonization and extinction probability estimates from multi-season models with data from 2005-2006 and 2005-2006 and 2011 probably shouldn't be explicitly compared with estimates from 2011-2013 because a slightly different study design was used, different wetlands were surveyed, and different observers conducted the surveys during the different monitoring periods. It would be worthwhile to continue to estimate and monitor colonization and extinction probabilities in the future, particularly given how low the most recent colonization probability estimates are and how much lower they are compared to extinction probability estimates.

Application of Parameter Estimates

Using the 2011-2013 copperbelly survey data and occupancy modelling, we were able to generate several population parameter estimates that can be used to monitor the Copperbelly Water Snake population in the study area over time. However, our parameter estimates should be applied to the entire copperbelly population in the study area with some caution at this time. 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 - 2013 were still primarily associated with recent wetland complexes (i.e., 67%-74% of the wetlands surveyed were part of recent wetland complexes), which were selected or targeted for surveys based on recent copperbelly observations and not randomly selected, the parameter estimates generated from these surveys may be biased for the entire population. Surveying more sample sites of historical or unknown copperbelly occupancy (i.e., high HSI-and low HSI- designated wetland complexes), which have been selected or ordered for surveys using a probabilistic sample design, within a given year in the future would produce a sample of sites and parameter estimates that would be more representative and less likely to be biased for the entire copperbelly population within the study area.

Our occupancy estimates also may be biased (i.e., overestimated) due to the movement of snakes among wetlands and violation of the closure assumption. The single-season and multiple season occupancy models have a number of underlying assumptions which include the following: (1)

occupancy status at each site does not change during the survey season, or the sites are "closed" to changes in occupancy; (2) there is no unmodeled heterogeneity in rate parameters (occupancy and detection, colonization, and extinction probabilities; (3) species are not falsely detected; and (4) species detection/detection histories at each site are independent (MacKenzie et al. 2002, 2003, 2006). MacKenzie et al. (2004a) noted that movement of animals among sites produces dependence among surveys and reduces the effective sample size, making estimates less precise than estimated (i.e., standard errors are greater than estimated). Roe et al. (2003, 2004) found that Copperbelly Water Snakes often moved among several wetlands within the same season and moved greater distances and used larger areas than Northern Water Snakes. Monfils and Lee (2011) noted that many of the survey sites used in our analysis were located close together and often within the range of distances that copperbellies have been observed moving within a season (or in some cases, within a day, Roe et al. 2004). Monfils and Lee (2011) had suggested using a minimum separation distance of approximately 450-500 m between survey sites to reduce the potential effects of snake movements on population estimates. While most wetland complexes and some wetlands surveyed within complexes were more than 450-500 m apart, we were not able to ensure that all wetlands surveyed within complexes were more than 450-500 m apart due to logistical and timing constraints. As a result, given the ecology of the species, it seems unlikely that some of the survey sites (i.e., wetlands) were independent and closed to changes in occupancy. However, copperbellies were documented at only some of the wetlands and the same wetlands within wetland complexes across multiple years despite wetlands being in close proximity to each other, which could indicate that wetlands within complexes were perhaps independent, at least in some cases. Also, Kendall (1999) and MacKenzie et al. (2006) found that parameter estimates could be unbiased if the movement of snakes into and out of the study area or sample units occurred randomly. Mazerolle et al. (2007) also contend that, even when assumptions are violated, estimation methods that account for detection probability, such as occupancy modelling, typically yield estimates with smaller biases than those based on *ad hoc* methods that don't incorporate detection probability, such as raw counts or observed occupancy.

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 by trying to ensure that each wetland was surveyed three times and that wetlands that were part of recent wetland complexes were surveyed during each year, but we still ended up with some missing data due to time, weather, landowner access issues, and other logistical constraints. Some wetlands were surveyed in 2011 but were not surveyed in 2012-2013 due to time constraints or lack of landowner access or permission to survey the site. Some wetlands were visited or surveyed only once in 2011, 2012, or 2013 and dropped from subsequent surveys because they did not represent or provide suitable habitat for copperbellies. Also, some wetlands were only surveyed in some years because of the sampling design (i.e., wetlands associated with unknown or historical wetland complexes were only surveyed once during the three-year monitoring period), or because we needed additional sites for monitoring (e.g., in 2013 when we surveyed a couple of new wetlands within a recent wetland complex because one of the landowners did not give permission their property). Missing data in the 2011-2013 dataset may have reduced the precision of some of the parameter estimates. As a result, more data from additional years of monitoring are needed to verify population parameter estimates and detect and monitor population trends over time.

Conclusions and Recommendations

Future Monitoring and Analysis

If the objectives of the copperbelly monitoring program continue to focus on tracking trends in the copperbelly population at known occupied sites and at a broader scale across the entire study area, surveying an adequate number of historical or unknown occupancy sites in addition to known or recent sites is critical for producing population parameter estimates that are not biased and are representative of the entire population. The current copperbelly monitoring protocol specifies that all recent or known occupied sites are surveyed every year, while historical or unknown occupancy sites are surveyed each year in the order in which they were randomly drawn, starting with sites with high HSI scores. Survey results from 2011 suggested that it might be challenging to monitor an adequate number of unknown/ historical occupancy sites after all recent sites are surveyed using a standard repeat survey design given limited funding, personnel, and other constraints. As a result, in 2012 and 2013, we utilized a mixed model study design in which recent wetland complexes/wetlands were surveyed every year (i.e., standard repeat survey design) but the historical or unknown wetland complexes/wetlands were surveyed using a rotating panel design in which a new or different subset of sites were surveyed each year following their randomly assigned survey order. Although a rotating panel design does introduce the possibility of spatial and temporal changes in occupancy becoming confounded (MacKenzie 2005), this sampling approach allows us to survey a greater number of historical or unknown sites across the study area to look for copperbellies at these sites and get parameter estimates that may be more representative of the entire population. Also, confounding spatial and temporal changes in occupancy has not been an issue because copperbellies have only been found in mostly the same small number of wetlands associated with known recent sites. We suggest continuing to use this sampling design if the monitoring program's objectives remain the same.

To produce population parameter estimates that are not biased and are representative of the entire population, we also suggest trying to survey a larger number of unknown/historical wetland complexes/wetlands per year so that they comprise a greater proportion of the total number of wetlands surveyed within a given year (e.g., ideally at least 50%). From 2011-2013, wetlands that were in unknown/ historical wetland complexes comprised only 26-33% of the total number of wetlands surveyed within each year, although they comprised 45% of the total number of wetlands surveyed across all three years (Table 1). Additional resources are needed though to increase the number of unknown/historical wetland complexes/wetlands surveyed within a year. For example, USFWS staff and additional IPFW personnel assisted with surveys in 2013 and increased the number of wetland complexes/wetlands that were surveyed that year, including the number of unknown/historical wetlands. Trained, reliable volunteers could be utilized to provide assistance with surveys to increase the number of wetlands surveyed.

The number of survey visits to conduct at each site may need to be revisited in the future. 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 (e.g., $\Psi \geq 0.75$) or detection probability was low (e.g., $p \leq 0.25$). 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 obtained from the 2011-2013 data. Using occupancy estimates about 0.10 to 0.20 and detection probability estimates of generally about 0.30 to 0.40 (except for 2012 variable occupancy model which ranged from 0.23-0.83) based on 2011-2013 data from all wetlands surveyed (excluding repeated count model estimates), the optimum number of survey visits per site ranged from 3 to 5 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 that were visited during 2011-2013, the number of sites that need to be or should be visited per year, and budgetary and personnel limitations, 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 possible, adding a fourth visit could be considered, especially earlier in the season when detectability seems to be higher. But this also might confound data comparison with earlier surveys.

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). Since detectability appears to be lower than 0.50 and 0.60 based on the 2011-2013 results, and the number of survey visits is somewhat 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 or year rather than the total number of sites surveyed over multiple years (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.

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. In 2012, we had an early spring, and copperbellies emerged earlier than in previous years. Adjusting the survey windows, particularly the start of the first survey window, based on local or annual weather conditions could be considered, but we would need to determine an approach for doing this. Effort should continue in the future to visit each site during each survey window to minimize missing observations. Since there was some evidence that detection probability may vary within a season and be higher for the first survey visit, every effort should be made to visit each selected or targeted survey site during the first survey window.

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, the order of sites, and time of day of surveys was not implemented in 2011 but was implemented to some degree in 2012 and 2013. When possible, this should continue to 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. In 2012 and 2013, a more consistent number of wetlands (2-9 wetlands, mean=7) per wetland complex were surveyed. We also did discuss standardizing the types of wetlands that would be surveyed for the surveys in 2011-2013 (e.g., focusing on small, isolated forested, shrubby, or open water wetlands or waterbodies and not large wetlands or riparian areas along streams or rivers). New surveyors or volunteers 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.

Site and survey covariates were not included in the 2011-2013 occupancy analyses but should be included in future occupancy analyses. Covariates that could be considered for future analyses include wetland type, distance to nearest wetland, number of wetlands in wetland complex, wetland complex HSI score, presence of northern water snakes, amount of forest cover within wetland complex, weather conditions, time of day, and surveyor experience. Potential site and survey covariates that might be important for 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.

Conservation and Management

Conservation of known occupied sites is critical for ensuring the continued persistence of the Copperbelly Water Snake population within the study area. The monitoring surveys in 2012-2013 continued to document low occupancy rates and small numbers of Copperbelly Water Snakes within the study area. Copperbellies also were documented at many of the same wetlands/wetland complexes from 2011-2013 and in 2005-2006. Occurring at a small number of sites and potentially the same sites year after year can result in increased vulnerability to stochastic processes and local extirpation. Targeted conservation and management efforts (e.g., habitat restoration, land or conservation easement acquisition, education and outreach) should focus on the known sites where copperbellies were documented during the 2011-2013 monitoring surveys and in 2005-2006, particularly sites where they have been regularly documented across years.

Because the number of copperbelly observations and number of individual wetlands and wetland complexes in which copperbellies were documented in 2011-2013 remain quite low and occupancy results from 2011-2013 suggest a potential decreasing trend, copperbellies should continue to be closely monitored. In order to detect population trends within the study area, additional years of monitoring data are needed. Increased or additional resources would allow more sites to be surveyed per year. Known or recent occupied sites should continue to be closely monitoring, but surveys of new or unknown sites also should continue to try to document additional sites at which copperbellies may occur. Additional surveys of wetlands in the vicinity of the new site where a copperbelly was found dead on the road in 2010 also should continue to determine if and where copperbellies occur within this site.

Investigating other survey methods or techniques that may enhance our ability to detect copperbellies or facilitate surveying more sites per year should be considered. For example, Kingsbury and Hall (2014 pers. comm.) have initiated efforts to investigate the use of wildlife cameras and basking platforms for surveying and detecting copperbellies at several known sites within the study area. If this method proves to be effective at detecting and surveying for copperbellies, this may help facilitate monitoring in the future. Cover boards or minnow traps also have been suggested as potential survey techniques to investigate, although survey methods should always minimize the potential for adverse impacts to copperbellies.

Additional targeted landowner contact and education and outreach efforts will likely be needed to conserve Copperbelly Water Snakes within the study area since most of the known occupied sites and the study area are privately owned. The conservation and recovery of the Lake Erie Watersnake (*Nerodia sipedon insularum*) also included targeted education and outreach of private landowners and local communities. Although there are ecological and socio-political differences between the Copperbelly Water Snake and the Lake Erie Water Snake and their respective project areas, the approach or model that was used for the Lake Erie Water Snake may provide lessons or examples of efforts that could be applied to copperbelly conservation efforts.

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APPENDICES

Appendix 1. Summary of wetland complexes that were surveyed in Michigan, Indiana, and Ohio as part of the Copperbelly Water Snake monitoring program from 2011-2013.

No.	Wetland Complex Group_ID	Wetland Complex Type/ Category	HSI Score Category	Survey Order	State	Last Survey Year	Permission granted 2011	Surveyed 2011?	Permission granted 2012	Surveyed in 2012?	Permission Granted 2013?	Surveyed 2013?
1	G4086	Recent	Low HSI	NA	IN	2013	Y	Y	Y	Y	Y	Y
2	G4087[1]	Recent	<0.60	NA	OH	-	-	N	-	N	-	N
3	G4863	Recent	<0.60	NA	OH	2013	-	N	-	N	Y	Y
4	G4864	Recent	High HSI	NA	OH	2013	Y	Y	Y	Y	Y	Y
5	G4865	Recent	High HSI	NA	OH	2013	Y	Y	Y	Y	Y	Y
6	G4866	Recent/ Historical?	Low HSI	NA	OH	2013	Y	Y	Y	Y	Y	Y
7	G4868	Recent	High HSI	NA	OH/MI	2013	Y	Y	Y	Y	Y	Y
8	G5392	Recent	<0.60	NA	OH	2013	-	N	-	N	Y	Y
9	G5696	Recent	High HSI	NA	MI	2013	Y	Y	Y	Y	MNA - Y; Brown - N	Y
10	G5708	Recent	High HSI	NA	MI	2013	Y	Y	Y	Y	MNA - Y; Brown - N	Y
11	G5719	Recent	Low HSI	NA	MI	2013	-	Y	-	N	Y	Y
12	G5733	Recent	Low HSI	NA	MI	2013	Y	Y	Y	Y	Y	Y
13	G5837	Recent	High HSI	NA	OH	2013	Y	Y	Y	Y	Y	Y
14	G5846	Recent	<0.60	NA	OH	2013	Y	Y	Y	Y	Y	Y
15	G5848	Recent	High HSI	NA	OH	2013	Y	Y	Y	Y	Y	Y
16	G5849	Recent	Low HSI	NA	MI	2013	Y	Y	Y	Y	Y	Y
17	G5933	Recent	High HSI	NA	MI	2013	Y	Y	Y	Y	Y	Y
1	G234	Unknown	High HSI	1	IN	2011	Y	Y	-	N	-	N
2	G4945	Unknown	High HSI	3	MI	2012	-	N	Y	Y	-	N
3	G6975	Unknown	High HSI	5	MI	2012	-	N	Y	Y	Y	Y
-	G5930	Unknown	High HSI	7	MI	-	-	N	-	N	-	N
4	G4085	Unknown	High HSI	9	IN	2011	Y	Y	-	N	-	N
5	G110	Unknown	High HSI	11	MI	2013	-	N	-	N	Y	Y
6	G5918	Unknown	High HSI	13	MI	2013	-	N	-	N	Y	Y
7	G128	Unknown	High HSI	15	IN	2013	-	N	-	N	Y	Y
-	G280	Unknown	High HSI	17	IN	-	-	N	-	N	-	N
-	G99	Unknown	High HSI	19	MI	-	-	N	-	N	-	N
-	G5018	Unknown	High HSI	21	MI	-	-	N	-	N	-	N
8	G4891	Unknown	High HSI	23	MI	-	-	N	-	N	Y	Y
9	G4142	Unknown	High HSI	25	IN	2011	Y	Y	-	N	-	N
10	G5731	Unknown	High HSI	27	MI	2011	Y	Y	-	N	Y	Y
-	G4359	Unknown	High HSI	29	OH							
11	G6226	Unknown	High HSI	31	MI	2012	-	N	Y	Y	-	N
12	G4775	Unknown	Low HSI	4	OH	2011	Y	Y		N		N
13	G4869	Unknown	<0.60	Not part of original/ selected sample	OH	2013	-	N	-	N	Y	Y
14	G5764	Unknown	High HSI	Not part of original/ selected sample	MI	2013	-	N	-	N	Y	Y

Appendix 2. Copperbelly Water Snake Monitoring Data Sheet for 2012-2013 surveys (page 1).

Copperbelly Water Snake Monitoring Data Sheet

Survey Date:		**County:**		**Surveyors:**	
Overall Visit Start Time:		**Wetland Complex Group ID:**	G	**T, R, S:**	
Overall Visit End Time:		**Status of Complex:**	Recent Historical Unknown High HSI Low HSI	**Site name (if applicable):**	
Survey Duration:		**Survey Visit # (circle):**	1 2 3		
Total Distance/Perimeter (m):					

Summary of Species:	Copperbelly Water Snake (CWS)	Northern Water Snake (NWS)	N. Ribbon Snake (NRS)	E. Garter Snake (EGS)	Bullfrog (BUF)	Green Frog (GRF)	Other Species:			
Total Number:										

Beginning Weather:	**Air temp (°F):**		**Sky Code:**		**Wind Code:**		**Precipitation Code:**	
Ending Weather:	**Air temp (°F):**		**Sky Code:**		**Wind Code:**		**Precipitation Code:**	

Start time	**End time**	**Wetland ID # (W #)**	**Community/ shoreline habitat type/ description (see codes on back)**	**Water level (Full, >50% Full, <50% Full, Dry)**	**Species observed**	**# observed**	**Latitude**	**Longitude**	**Photo ID #**	**Comments (GPS waypoint(s), new/unmapped wetland, mapping errors, etc.**

Appendix 2. Copperbelly Monitoring Survey Data Sheet for 2012-2013 surveys (continued – page 2).

Sky Codes:	**Wind Codes (Beaufort wind scale):**
0 = Sunny/clear to few clouds (0-5% cloud cover)	0 = Calm (< 1 mph) smoke rises vertically
1 = Mostly sunny (5-25% cloud cover)	1 = Light air (1-3 mph) smoke drifts, weather vane inactive
2 = Partly cloudy, mixed or variable sky (25-50%)	2 = Light breeze (4-7 mph) leaves rustle, can feel wind on face
3 = Mostly cloudy (50-75%)	3 = Gentle breeze (8-12 mph) leaves and twigs move, small flag extends
4 = Overcast (75-100%)	4 = Moderate breeze (13-18 mph) moves small tree branches, twigs & leaves, raises loose paper
5 = Fog or haze	5 = Strong breeze (19-24 mph) small trees sway, branches move, dust blows
	6 = Windy (> 24 mph) larger tree branches move, whistling
Precipitation Codes:	**General Habitat Types(NWI) (can use other habitat types or descriptions as well):**
0 = None	**PFO** = Palustrine Forested Wetland: standing water at least part of the year, tree canopy cover exceeds 30%.
1 = Mist	**PSS** = Palustrine Scrub-Shrub Wetland: shrub cover exceeds 30%, but tree cover does not.
2 = Light rain or drizzle	**SDG** = Palustrine Emergent Wetland dominated by sedges.
3 = Heavy rain	**CAT** = Palustrine Emergent Wetland dominated by cattails.
4 = Snow/hail	**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 (W #) in Suitability_model_full shapefile. (In some cases, may have used Wet_id_num in the past.)

For new wetlands surveyed in the field that were not previously mapped or assigned Wetland ID #, please assign ID # by adding A, B, C, etc. to closest wetland # - e.g., 245A.

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.