Anuran Community Occupancy Dynamics in Wayne National Forest in Southeast Ohio

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Andrew Connolly

Ohio University, Biological Sciences, Athens, OH

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Abstract

Amphibians are indicator species of ecosystem health due to their high susceptibility to changing environmental conditions, whether it be natural or anthropogenic changes. Amphibians also play a key role in many ecosystems, such as moving nutrients between terrestrial and aquatic habitats. It is important to understand how populations change over time in response to different environmental pressures to support successful land management strategies. Wayne National Forest (WNF) in Southeast Ohio harbors a rich amphibian fauna, and wildlife managers monitored pond-breeding anuran (frog) species to determine the best forest management strategies for their protection. The goal of this project was to quantify pond-breeding amphibian community dynamics in WNF in relation to different land management strategies and environmental predictors using a hierarchical modeling framework.

Using the North American Amphibian Monitoring Program protocol, data was collected at 30 sites March through June from 2005-2018. A total of 14 species were studied, with zero detections for the Eastern Spadefoot Toad (*Scaphiopus holbrookii)* to hundreds for species such as the Spring Peeper (*Pseudacris crucifer)*. We ran dynamic occupancy models and then using AIC values determined model suitability and what abiotic factors were the best predictors of occupancy. Month and air temperature, for example, were the best predictors of American Toad occupancy. Using these results, we will then share them with WNF to aid them in determining effective land management strategies and to assist them in resecuring federal funds for amphibian monitoring programs.

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Introduction

Amphibians are the most imperiled taxa and are faced with a wide array of threats to their persistence, including climate change, habitat loss and alteration, disease and pollution (Stuart et al. 2014). Their permeable skin and biphasic (aquatic and terrestrial) life cycles (Wilbur 1980) makes amphibians susceptible to many stressors and that can act independently or in synergy across different life stages (Earl and Semlitsch 2013, Boes and Benard 2014, O'Regan et al. 2014, Thompson and Popescu 2021). Amphibians not only act as sentinel of environmental change in many systems (Collins and Storfer 2003), but also have significant contributions to ecosystem services and tropic webs. For example, annual breeding migrations move organic matter and nutrients between habitats and can affect biogeochemical cycles and ecosystem processes (Berven 2009, Capps et al. 2015, Earl et al. 2022). Thus, the loss of amphibian populations can have profound effects on the ecosystems they inhabit and can contribute to a host of other unknown effects. Additionally, anurans serve as prey for a host of terrestrial and aquatic species (Somers and Purves 1996, Corlett 2011, Costa et al. 2021), and their loss can have cascading effects up and down the trophic levels.

Monitoring trends in amphibian populations is a critical component of amphibian conservation. Populations of most amphibian species are known to fluctuate greatly both temporally and spatially (Berven 1990, Werner et al. 2009, Kupferberg et al. 2012, Earl et al. 2022). There is a need for long-term data to analyze for changes within communities, with calls for increased monitoring found across decades (Blaustein et al. 1994, Weir et al. 2005). As such, long-term data collected across larger geographic extents and temporal scales using powerful monitoring protocols can signal declines as well as recoveries in amphibian population, which can trigger management and conservation actions. When identifying the effects of diseases such as those in the *Ranavirus* genus, and the chytrid fungus, long-term data provides important insights into what species are affected, and what pathogens disrupt communities the most (Bosch et al. 2018, 2021). Long-term data can also be useful in determining persistence of species and changes in diversity on the local level (Petranka et al. 2007), and programs like the North American Amphibian Monitoring Program (NAAMP), a standardized data collection protocol, can also be used to model detection and occurrence probability (MacKenzie et al. 2002, Weir et al. 2012, Ondei et al. 2018) and comparing data across years and decades. Long-term data aids in monitoring for changes in these values and analyzing for significant differences with local populations and amphibian communities.

Many species of calling Anurans can be identified by their breeding calls, which are unique to each species (Mossman et al. 1998, Weir et al. 2009). The North American Amphibian Monitoring Program was created in order to monitor trends in amphibian occupancy in the conterminous US, and to assess changes in local communities of calling amphibians utilizing the unique calls of breeding amphibians. (Weir et al. 2005). NAAMP is something that can be taught easily and requires few resources to learn and conduct surveys, thus making it an optimal tool for low budget or low volunteer data collection. The common sampling method enables easier comparisons across surveys and standardizes collection methods within the field. This protocol was deployed for various lengths of time across North American landscapes.

NAAMP methods rely on repeated surveys of the same sites within a given year or anuran calling season. This repeated-visit approach allows for accounting for imperfect detection via occupancy modeling (MacKenzie et al. 2002). When monitoring the same sites across year, this statistical framework can be extended to dynamic occupancy models that concomitantly estimate population and metapopulation processes such as colonization and extinction (MacKenzie et al. 2003).

In this study, we used a 15-year dataset (2005-2018) of repeated call surveys of 14 species of anurans (Table 1) at 30 ponds located on the Wayne National Forest in SE Ohio. This monitoring program was originally started in 2005 to understand the effects of different land management strategies around sources of water on anurans in southeast Ohio. Survey sites were selected based on accessibility and water source availability, and Wayne National Forest staff and volunteers monitored sites following NAAMP protocol from March through June of each year. The main objectives of this research were: (1) to characterize the makeup of the pond-breeding anuran community in SE Ohio, (2) to determine anuran occupancy trends in southeast Ohio, (3) to evaluate environmental predictors for occupancy and extinction rates, and (4) to evaluate survey specific covariates explaining detection and fine-tune future surveys. Overall, this research provides quantitative evidence for anuran population trends in SE Ohio and produces baseline information for fine-tuning surveys to meet other management and conservation objectives, such as changes in breeding phenology and detection.

Methods

Site selection

The Athens district of Wayne National Forest began surveys in 2005, using the North American Amphibian Monitoring Program (Weir et al. 2009) as the basis for their site selection criteria. Wayne National Forest (WNF) employees selected sites that were close to a source of water, had public access, and occurred within the boundaries of Wayne National Forest. Thirty sites were selected across Dover, Ward, and York townships in southeast Ohio, and they were divided into three groups of ten sites (Fig. 1).

York Route 91 sites were primarily located south of US-33 and the Hocking River and encompass regions of York Township and Nelsonville (Fig. 1). The survey sites included a mix of natural and man-made water sources and were located around the Hocking College Campus in Nelsonville OH. Dover Route 104 sites were located north of US-33 and the Hocking River and were primarily northeast of State Route 13 (Fig. 1). Sites were in and around Chauncey and Dover Township Ohio, as well as surrounding forested areas. Ward Route 119 sites were located North of US-33 and the Hocking River and encompassed regions of Carbon Hill-Buchtel and Ward Township (Fig. 1). Many of the sites were located close to developments such as homes, roads, and man-made culverts.

Data Collection

Anuran call surveys were conducted by volunteers once per month from March until June during the third week of each month, between 2005 and 2018. During this period, over 160,000 data points were collected for use by Wayne National Forest.

There was a gap in 2019 and 2020 due to COVID related restrictions, with data being collected again in 2021, and likely ongoing into the future. Here we are presenting data from 2005 through 2018 as it is a complete data set, which allowed us to estimate extinction and colonization dynamics. All surveys started one hour after sunset, and occurred only when temperatures were >50 degrees Fahrenheit, during calm wind conditions, and not during heavy rainfall events, as high winds and rains interfered with surveyors' abilities to hear anuran vocalizations (Weir et al. 2009). In most years, the three routes were surveyed during the same night in any given month.

Observers followed each route starting one hour after sunset and the start of the route was random across surveys. The completion of any ten-site route took approximately two to three hours. At each site air and water temperature, as well as sky conditions were recorded on the data sheet. Sky and wind conditions followed the North American Amphibian Monitoring Program protocol. Surveys occurred when wind speeds were less than a 4 on the Beaufort wind scale, or 20.9 km/hr (Weir et al. 2009). Sky conditions were labeled as clear, partly cloudy, cloudy, or raining. Upon arrival at the sites, observes turned on electronic recorders and listened to vocalizations for three minutes in silence, noting which species they heard and their relative call abundance. Call abundance was ranked on a scale of 0 to 3 based on the NAAMP Protocol (Weir et al. 2009). 0 = no individuals of a given species recorded; 1 = no overlapping calls and the exact number of individuals was recorded; 2 = some overlapping calls and the number of individuals was estimated; and 3 = a continuous chorus that made it impossible to discern the exact number of individuals present.

Site specific variables

Site specific variables were extracted from the National Land Cover Database (Homer et al. 2020) to determine local landcover composition within 100, 250, and 500 meters circular neighborhoods using ArcGIS 10.8 (ESRI, Redlands CA) as it is known to influence spatial patterns of Anuran occupancy (Mazerolle et al. 2005). We condensed types of land cover due to low or non-existent coverage and due to the low importance of some landcover types on anuran occupancy (Table 2).

We also extracted information on the presence or absence of beaver disturbance, for beaver modification of lotic and lentic systems is known to increase amphibian diversity at local and landscape scales (Russell et al. 1999, Stevens et al. 2006, 2007, Cunningham et al. 2007, Karraker and Gibbs 2009, Popescu and Gibbs 2009, Wright et al. 2002). We also considered the number and type of water sources based on site surveys conducted by Wayne National Forest (Schultes 2005a, 2005b, 2005c). Water sources were classified as natural creek, pond and wetland, manmade, ephemeral pond, and unknown. Additionally, using Google Earth Pro (*Google Earth Pro* 2021), we measured the distance from each site to the nearest wetland (from the National Wetland Inventory), nearest pave road, and other human development.

Statistical analysis

In 2020, Wayne National Forest turned over the data to us for analysis, to understand how communities have changed over time, and to determine Anuran occupancy rates in Southeast Ohio. We selected five species of interest, the American Bullfrog (*Rana catesbeiana*), the American Toad (*Anaxyrus americanus)*, the Gray

Tree Frog (*Hyla versicolor),* the Green Frog (*Rana clamitans)*, and the Pickerel Frog (*Rana palustris)* based on naïve occupancy for further analysis.

To evaluate the trends in pond occupancy through time as well as colonization (γ) and extinction (ε) rates, we utilized a dynamic occupancy model (MacKenzie et al. 2003, MacKenzie and Royle 2005, Schmidt and Pellet 2005, Popescu et al. 2012) within the program R (R Core Team 2021). We utilized a multi-season occupancy model within package *unmarked* (Fiske and Chandler 2011). This allowed us to estimate occupancy (Ψ) at a given site for a given species while accounting for imperfect detection (*p*) (Murray et al. 2015), which we modeled as a function of survey specific variables recorded during each call survey (Table 2), scaled by centering on the mean and normalized by dividing by the standard deviation.

We identified the best covariates for detection for each species from the four detection variables. We then ran a Spearman test using package *Hmisc* (Harrell Jr. 2021) to find correlations between variables and to determine what variables could not run together. Using these variables, we fit 22 models to each species with combinations of site variables and ranked them with AICc values (Hurvich and Tsai 1989, Murray et al. 2015) using the package *MuMIn* (Barton 2020). 11 of the models utilized ε=1 and the other 11 utilized ε=YEARS, to account for annual changes in extinction probability. For each species we also then calculated colonization ($\gamma \pm$ SE), extinction ($\varepsilon \pm$ SE), and mean occupancy probability ($\Psi \pm$ SE) for the top model identified.

Results

Species richness

Mean species richness for York Route 91 was 3.5 $\pm$ 0.14 (SE). Mean species richness for Dover Route 104 was 3.5 $\pm$ 0.17. Mean species richness for Ward Route 119 was 3.5 $\pm$ 0.20. The maximum species detected at a site across transects occurred at Ward Route 119, site 3 in 2011 where 9 species were detected over the four-month period. Mean species richness at this site was 5.8 $\pm$ 0.55 (SE).

Within each route, there was great variation among the sites on the number of species detected (Fig. 2). York Route 91 had a maximum mean species richness at site 7 ($\bar{x} = 4.9 \pm 0.36$) , and a minimum species richness at site 1 ($\bar{x} = 1.9 \pm 0.27$). Dover Route 104 had a maximum mean species richness at site 6 ($\bar{x} = 5.7 \pm 0.37$) and minimums at sites 8 ($\bar{x} = 1.4 \pm 0.39$) and 10 ($\bar{x} = 1.4 \pm 0.37$). Ward Route 119 had a maximum mean species richness at sites 3 ($\bar{x} = 5.7 \pm 0.55$) and 6 ($\bar{x} = 5.8 \pm 0.46$), and a minimum at a site 5 with 0 detections across the surveys.

There were 30 instances where no species were detected the entire year with 3 at Route 91, 9 at Route 104 and 18 at Route 119. These were spread across sites, with 3 sites in Route 91 4 in Route 104 and 3 in Route 119.

Occupancy and detection probabilities

We detected 13 of the 14 species of interest during one or more surveys over the course of the surveys (Table 3). The most detected species was the Spring Peeper, which was found at 24 (19= min, 27=max) sites on average per year. The Spadefoot Toad (*Scaphiopus holbrookii)* which is considered endangered in Ohio (Ohio

Department of Natural Resources Division of Wildlife 2020) was not detected by researchers during surveys. The American Bullfrog, American Toad, Gray Tree Frog, Green Frog, and Pickerel Frog were also among the most detected species. The best predictor for occupancy across all species was distance to nearest wetland, which was negatively associated with occupancy for the American Toad, Gray Tree Frog and the Pickerel Frog and positively associated for the American Bullfrog and Green Frog. (American Bullfrog= 0.522, American Toad = -0.594, Gray Tree Frog= -0.620, Green Frog = 0.386, Pickerel Frog = -0.0338). Pond occupancy was also positively associated with distance to nearest road for all species (American Bullfrog = 1.24, American Toad = 2.91, Gray Tree Frog = 0.69, Pickerel Frog = 5.31, Green Frog = 1.37).

The mean occupancy probability for the American Bullfrog in year one (2005) (Ψ) was 0.5573 $\pm$ 0.1092 (SE) for the top model. For the American Toad, the year one mean occupancy probability was 0.8965 $\pm$ 0.0784 for the top model. The Gray Tree Frog year one mean occupancy probability was 0.715 $\pm$ 0.1258 for the top model. The Green Frog year one mean occupancy probability was 0.6581 $\pm$ 0.1007 for the top model. The Pickerel Frog year one mean occupancy probability was 0.6249 $\pm$ 0.086- for the top model (Fig. 3).

Out of the four survey specific variables, *temperature* and *month of the year* together were the most important factors in detection probability (*p*) for the American Bullfrog, the American Toad, and The Gray Tree Frog, while *time* and *month of the year* were the most important factors in detection probability of the Green Frog and Pickerel Frog (Table 4). Temperature is positively associated with detection probability for the American Toad, the American Bullfrog and the Gray Tree Frog (0.133, 0.053, 0.099 respectively). Time is negatively associated with detection probability for the Green Frog and Pickerel Frog (-0.00256, -0.00076). Month's influence on detection probability varied by month and species March through June (American Toad = 0.866, 1.209, -1.384, -4.246, American Bullfrog = -6.700, 4.367, 8.172, 7.485, Gray Tree Frog = -5.172, -2.072, -0.776, -1.308, Pickerel Frog = 5.515, 6.381, 3.167, -3.925, Green Frog = -5.002, -2.280, -0.107, -0.168 March-June respectively). The most detectable species was the Green Frog ($p = 0.4628$), while American Toads and Gray Tee Frogs had lower detection probability overall (p = 0.144 and 0.2207, respectively; Table 5).

Colonization and extinction probabilities

Extinction and colonization rates for all species did not vary across years. In general colonization and extinction rates were low (i.e., low turnover; Table 5). Extinction rates were slightly higher than colonization rates for American Bullfrog ($\gamma = 0.043 \pm 0.017$; $\varepsilon = 0.056 \pm 0.019$) and Pickerel frogs ($\gamma = 0.0884 \pm 0.026$ and $\varepsilon = 0.112 \pm 0.035$). For all the other species considered here colonization rates were higher than extinction rates (Table 5). Despite the variation in extinction and colonization rates, there were no strong trends in occupancy through time (Figure 3). Most species stayed stable or showed a slight decline, although not significant statistically (Figure 3).

Discussion

This study was the first exploring Anuran community dynamics occupancy in Southeast Ohio using long terms data collected on the Wayne National Forest. Thirteen of the fourteen species present in southeastern Ohio were detected over a 14-year study, with the exception of the Eastern Spadefoot Toad, an endangered species in the state of Ohio (Smith et al. 1973, Ohio Department of Natural Resources Division of Wildlife 2020). For 5 species there was sufficient data to implement dynamics occupancy models, and it was found that occupancy was stable throughout the study period. Colonization and local extinction rates were low, suggesting low turnover in these species. The surveys started at the end of March each year and likely missed some early breeding species in some instances (e.g., wood frogs, which are early breeders).

Distance to nearest wetland was the best variable for explaining occupancy for all five species of interest analyzed using dynamic occupancy models (American Bullfrog, American Toad, Gray Tree Frog, Pickerel Frog, Green Frog). The five species indicated that distance to nearest wetland was important in determining species occupancy, a characteristic previously documented in other locations and species of anurans (Hamer and Mahony 2010, Scherer et al. 2012). Distance to nearest wetland which was negatively associated with occupancy for the American Toad, Gray Tree Frog and the Pickerel Frog and positively associated for the American Bullfrog and Green Frog. This indicates that connectivity and distance to other wetlands are important factors affecting the persistence of these species in the Wayne National Forest. The loss of wetlands could affect the overall occupancy of these species due to fewer dispersal opportunities for those species whose occupancy is negatively correlated to distance to nearest wetland, the American Toad, Gray Tree Frog, and the Pickerel Frog. Wetlands are some of the most imperiled habitats on the planet, with the United States seeing a net loss of 9,000,00 acres, or 10% of their wetlands occurring in the mid to late 20th century (Tiner 1984). With access to wetlands due to geographic characteristics or denial by landowners difficult to obtain, it is unknown the full extent of wetland's status in the present day, thus the monitoring and conservation of the accessible lands and species within it is important (Olsen et al. 2019).

Pond occupancy was also positively associated with the distance to nearest roads within our top models for all species. Landscapes in southeast Ohio are fragmented by urban and agricultural areas (Homer et al. 2020), as well as a very dense network of roads with varying traffic intensity. Roads are known to pose challenges to amphibian conservation, as they are often one of the main sources of mortality, particularly during breeding migrations (Fahrig et al. 1995, Gibbs 1998, Vos and Chardon 1998, Carr and Fahrig 2001, Hels and Buchwald 2001, Gibbs and Shriver 2005, Eigenbrod et al. 2008, Karraker et al. 2008, Petrovan and Schmidt 2016). Roads have a strong effect on ecosystems, an effect that is often negatively correlated with species richness and individual fitness (Forman and Alexander 1998, Trombulak and Frissell 2000).

Detection of the five species considered here varied with *temperature during the survey (TEMP)* and *month of the year (MONTH*). For three of the five species of interest, *time after sunset (TIME)* and *month of the year* together were most important in determining detection probability (*p*) for two of the species (Table 4). TEMP and MONTH were the most important factors for the American Toad, the American Bullfrog, and the Gray Tree Frog, while TIME and MONTH were the most important factors for the Green Frog and Pickerel Frog. Temperature is positively associated with detection probability for the American Toad, the American Bullfrog and the Gray Tree Frog. Time is negatively associated with detection probability for the Green Frog and Pickerel Frog. Temperature is an important factor in amphibian calling activity (Gayou 1984), and as climates change influences our ecosystems in coming decades, it is important to monitor for changes in breeding phenology of amphibians, particularly in relation to predators and prey whose phenology may not change. It was also demonstrated that timing of surveys has an impact on detection of species. Therefore it is important that researchers conducting frog call surveys are in the field at appropriate times in order to increase detection probability and to limit imperfect detection (MacKenzie et al. 2002, 2003). Surveys should be rotated monthly and annually, going 1 to 10 then 10 to 1 or conducted from a randomly selected starting point, through to the end to limit the effect time after sunset has on detection, and to increase the probability of surveying at a time suitable to all species. Researchers in Southeast Ohio should also start surveys one month earlier and end at minimum one month later to account for early calling and late calling species. These surveys likely missed the earliest breeding species, the wood frog, in many years. Wood frog breeding season is subject to high fluctuation, as it is closely tied to ambient temperature (Bernard 2015, Larsen et al. 2021), and also is very brief (up to 1 week in our study area). Thus, it is possible that the breeding season was completely missed during years with early onset of breeding. In addition, breeding phenology shifts have been shown for many anurans, with many species breeding earlier in the season due to climate change(Gibbs and Breisch 2001, Beebee 2002, Paton and Crouch 2002, Todd et al. 2011, Rudolf 2018).

We found that colonization rates were greater than the extinction rates for the American Toad and Gray Tree Frog, yet we observed a stable or slightly declining trend in occupancy through time (Figure 3). While colonization enables the larger population to persist, the values were quite low for both parameters, and there is likely un-modeled heterogeneity in these parameters that could not be captured by our variables. In contrast, colonization rates were lower than extinction rates for the American Bullfrog, showcasing a slight decline in occupancy through time (Figure 3). The Green Frogs had a relatively stable occupancy over time, suggesting latent factors are affecting occupancy, and reducing the total number of occupied patches.

The study was limited in spatial extent (30 sites selected based on accessibility in a relatively homogenous landscape), thus the inferences drawn here have limitations. To improve on the survey, there is a need to increase the number and spatial extent of survey sites. The project does however take strength from its long-term data collection, a collection spanning 14 years and with plans to continue it moving forward using a new data set that was started in 2021.

Management implications

As the Wayne National Forest and a network of volunteers continue to collect data moving forward, it is important to ensure that additional factors are explored, and to ensure surveys are conducted at appropriate times. These surveys have the potential to fill gaps in knowledge on breeding amphibians in southeast Ohio and can provide information on how climate change and land management strategies affect anuran occupancy. As the first long-term amphibian monitoring program in Ohio, this work provides a baseline on anuran occupancy, and on breeding seasonality. We recommend that land managers monitor trends and changes in colonization and extinction rates and determine if land management strategies have been effective. As amphibians are indicator species of ecosystem health, they provide a valuable insight into potential threats posed to an ecosystem.

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Table 1: Species were selected based on prior detection in southern Ohio, and into West Virginia.

Figure 1: Survey sites are located in the Athens Unit of Wayne National Forest, in and around the Hocking River area. Sites contain a mix of natural and man-made water sources, and contain a patchwork of primarily forested, open, and developed land.

Table 2: Survey and site-specific variables used for modeling detection probability (p) and occupancy (Ψ) of Anurans in Wayne National Forest.

Figure 2: Species richness by year for Route 91, 104, and 119 sites.

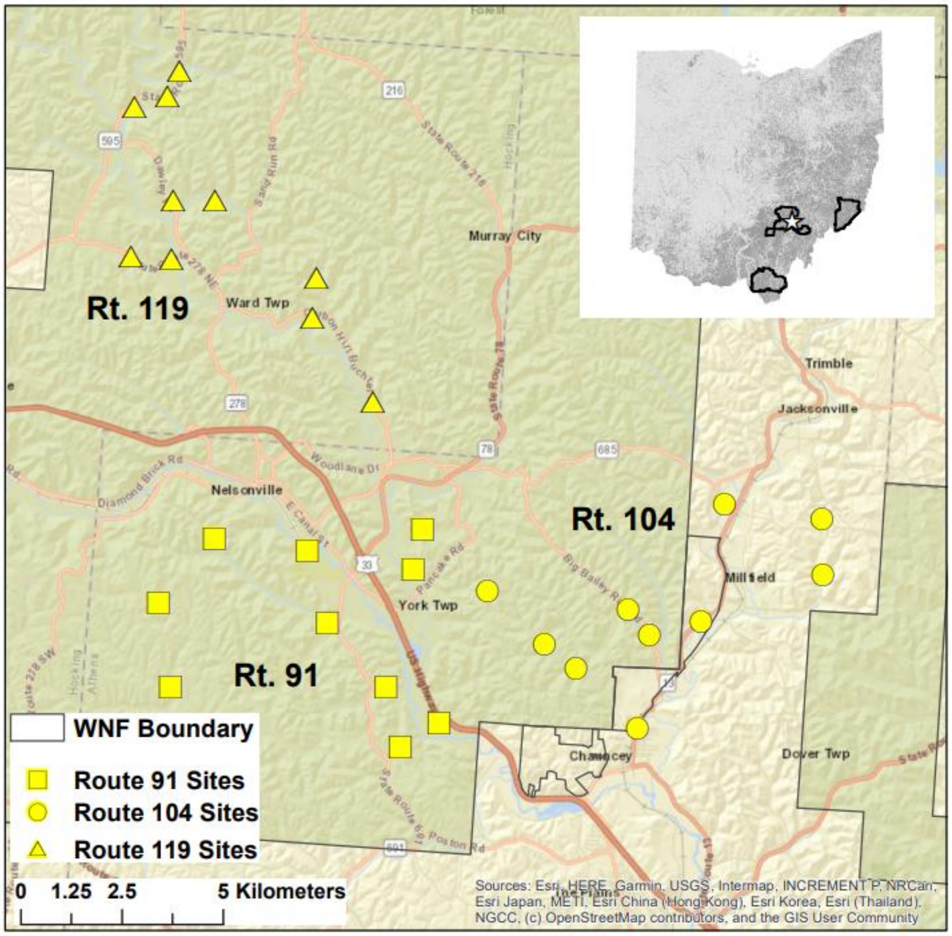
Table 3: Naïve (observed) occupancy through time; number of ponds = 30

Table 4: Top three models that may explain occupancy for species of interest in Wayne National Forest in Southeast Ohio.

Figure 3: Mean occupancy probability by year for the 5 species of interest in Southeast Ohio. Top to Bottom: American Bullfrog, American Toad, Gray Tree Frog, Green Frog, Pickerel Frog.

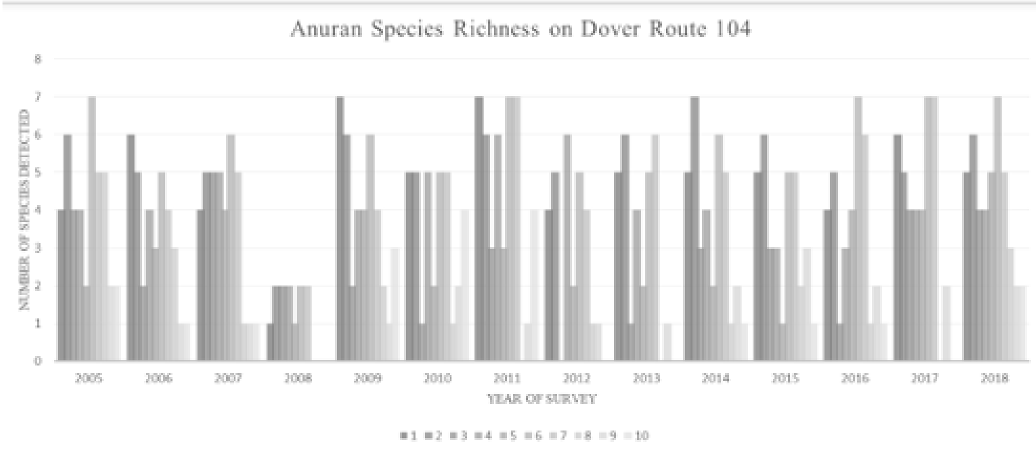
Table 5: Detection probability, colonization, and extinction rates for the 5 species of interest.

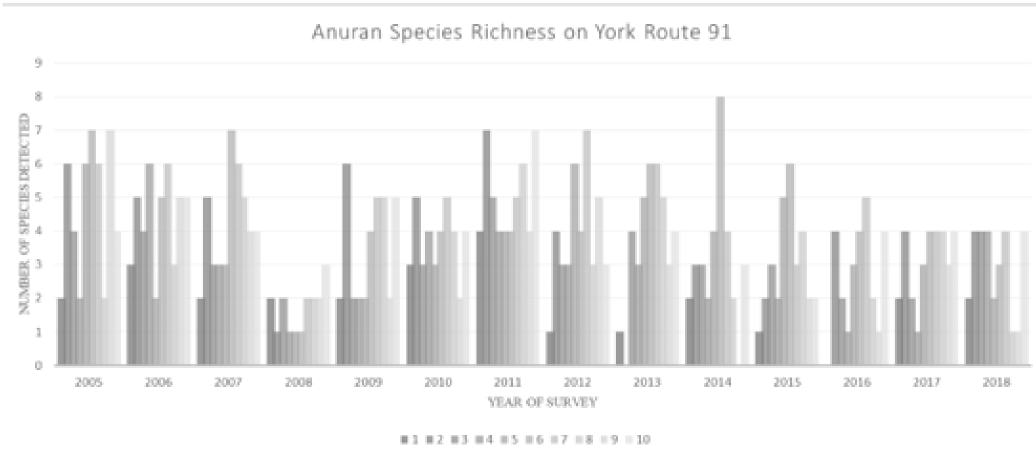
Species Common Name	**Species Scientific Name**	**Prior Species Detection Records**
American Toad	*Anaxyrus americanus*	Green 1948, Johnson 2003, Gooley 2013, Powell et al. 2016
American Bullfrog	*Lithobates catesbeianus*	(Gooley 2013, Powell et al. 2016)
Blanchard's Cricket Frog	*Acris blanchardi*	(Lehtinen and Witter 2014)
Cope's Gray Treefrog	*Hyla chrysoscelis*	Costanzo et al. 1992
Eastern Spadefoot Toad	*Scaphiopus holbrookii*	Green 1948, Smith et al. 1973, Johnson 2003, Gooley 2013
Fowler's Toad	*Anaxyrus fowleri*	Thornhill 1985, Smith and Green 2004, Powell et al. 2016
Gray Treefrog	*Hyla versicolor*	Gatz Jr. 1981, Little et al. 1989, Matson 1990
Green Frog	*Rana clamitans*	Gooley 2013, Powell et al. 2016
Leopard Frog	*Rana pipiens*	Powell et al. 2016
Mountain Chorus Frog	*Pseudacris brachyphona*	Hoffman 1980, Ospina et al. 2020
Pickerel Frog	*Rana palustris*	Schaff Jr. and Smith 1970, Gooley 2013, Powell et al. 2016
Spring Peeper	*Pseudacris crucifer*	Gooley 2013, Powell et al. 2016
Western (Midland) Chorus Frog	*Pseudacris triseriata*	Thomas 1951, Platz and Forester 1988, Powell et al. 2016
Wood Frog	*Lithobates sylvaticus*	Powell et al. 2016

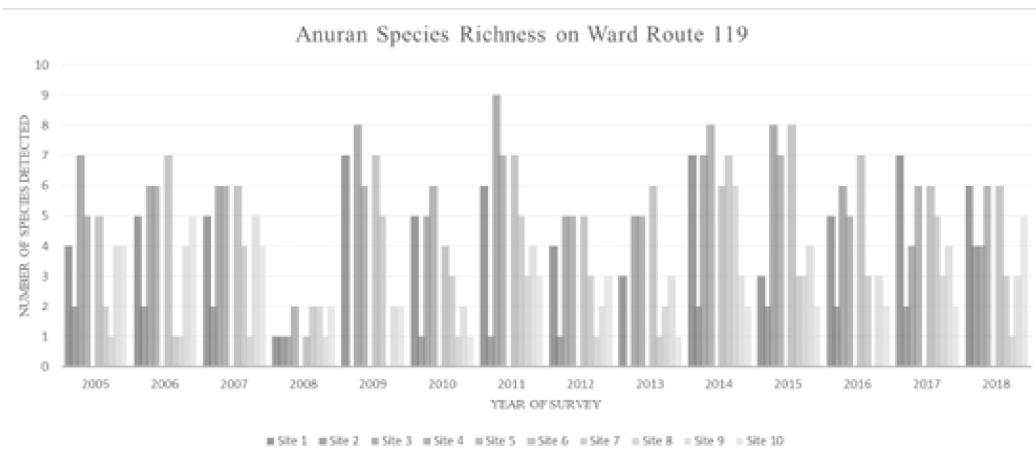

Rt. 119
Rt. 91
Rt. 104
Murray City
Ward Twp
Nelsonville
York Twp
Trimble
Jacksonville
Millfield
Chauncey
Dover Twp
WNF Boundary
Route 91 Sites
Route 104 Sites
Route 119 Sites
0 1.25 2.5 5 Kilometers
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Variable	Description	Range	Data Source
Detection (*p*) variables			
MONTH	Survey Month (Mar. = 1, Apr. = 2…)	1 - 4	
TIME	Minutes After Sunset	0 - 273	
TEMP	Temperature in Degrees Fahrenheit	35 - 80	
SKY	Sky Conditions (Clear, Cloudy, Partly Cloudy, Rain)	1-4	
Occupancy (Ψ) variables			
100.dev	Low developed in 100-meter buffer		NLCD
100.devhigh	High developed in 100-meter buffer		NLCD
100.for	Forested land in 100-meter buffer		NLCD
100.opn	Open land in 100-meter buffer		NLCD
100.agr	Agriculture land in 100-meter buffer		NLCD
100.wet	Wetlands in 100-meter buffer		NLCD
250.dev	Low developed in 250-meter buffer		NLCD
250.devhigh	High developed in 250-meter buffer		NLCD
250.for	Forested land in 250-meter buffer		NLCD
250.opn	Open land in 250-meter buffer		NLCD
250.agr	Agriculture land in 250-meter buffer		NLCD
250.wet	Wetlands in 250-meter buffer		NLCD
500.dev	Low developed in 500-meter buffer		NLCD
500.devhigh	High developed in 500-meter buffer		NLCD
500.for	Forested land in 500-meter buffer		NLCD
500.opn	Open land in 500-meter buffer		NLCD
500.agr	Agriculture land in 500-meter buffer		NLCD
500.wet	Wetlands in 500-meter buffer		NLCD
beaver	Beaver activity presence or absence	0-1	WNF
dw	Distance to nearest adjacent wetland (m)	13.86 – 871.26	GE
dr	Distance to nearest road (m)	0 - 209.91	GE
dd	Distance to nearest development including road (m)	0 - 209.91	GE
num	Number of water sources to site	1-3	WNF

NLCD = National Land Cover Dataset
GE = Google Earth
WNF =Wayne National Forest

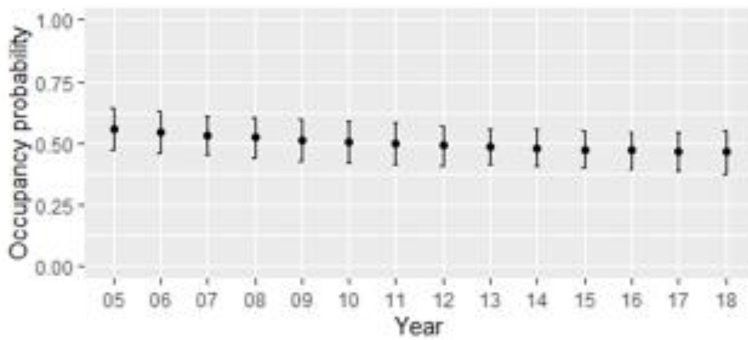

Anuran Species Richness on Dover Route 104
NUMBER OF SPECIES DETECTED
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
YEAR OF SURVEY
1 2 3 4 5 6 7 8 9 10

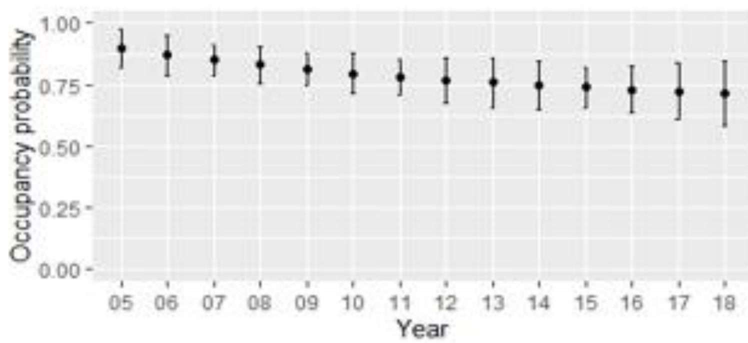

Anuran Species Richness on York Route 91
NUMBER OF SPECIES DETECTED
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
YEAR OF SURVEY
1 2 3 4 5 6 7 8 9 10


Anuran Species Richness on Ward Route 119
NUMBER OF SPECIES DETECTED
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
YEAR OF SURVEY
Site 1 Site 2 Site 3 Site 4 Site 5 Site 6 Site 7 Site 8 Site 9 Site 10

SPECIES	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
American Toad	11	4	22	9	19	3	15	2	3	10	6	11	12	1
Bullfrog	12	10	13	12	13	12	13	12	11	12	5	7	10	10
Common Gray Tree frog	11	9	9	12	11	10	10	12	8	8	10	6	7	13
Cope's Gray Tree frog	6	4	2	3	5	7	6	2	12	11	8	3	5	13
Cricket Frog	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Fowler's Toad	0	0	0	0	1	1	2	1	0	0	1	1	0	0
Green Frog	17	17	17	20	16	14	19	15	14	17	13	14	16	15
Leopard Frog	1	2	2	3	0	0	3	1	0	0	0	0	1	3
Mtn. Chorus Frog	1	3	2	1	2	1	3	8	2	2	1	0	1	3
Pickerel Frog	9	9	12	10	9	7	8	11	10	10	12	12	11	4
Spadefoot Toad	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spring Peeper	27	24	26	26	22	24	27	24	19	24	26	23	24	23
Western Chrous Frog	0	0	0	4	0	0	1	0	0	0	0	0	0	2
Wood Frog	3	4	1	4	5	2	4	0	3	8	13	2	2	6

Ψ formula	**ε formula**	**df**	**LogLik**	**AICc**	**Δ**	**Weight**
American Bullfrog (*Rana catesbeiana)*- p formula: TEMP + MONTH						
s.dw	1	10	-378.2	788.0	0.00	0.531
s.dw + s.dr + s.dd	1	12	-373.8	790.0	1.94	0.202
s.dw + s.dr	1	11	-376.7	790.1	2.05	0.191
American Toad (*Anaxyrus americanus)*- p formula: TEMP + MONTH						
s.dw	1	10	-456.7	945.0	0.00	0.626
s.dw + s.dr	1	11	-455.5	957.6	2.62	0.169
s.dw + s.dd	1	11	-455.7	948.1	3.10	0.133
Gray Tree Frog (*Hyla versicolor)*- p formula: TEMP + MONTH						
s.dw	1	10	-503.7	1039	0.00	0.557
s.500.dev + s.500.opn+ s.500.devhigh	1	12	-499.0	1040	1.51	0.262
s.dw + s.dr	1	11	-503.1	1043	4.01	0.075
Green Frog (*Rana clamitans)*- p formula: TIME + MONTH						
s.dw	1	10	-623.9	1279	0	0.634
s.dw + s.dr	1	11	-622.5	1282	2.23	0.208
s.dw + s.dd	1	11	-623.1	1283	3.46	0.11
Pickerel **Frog (*Rana palustris)*- p formula: TIME + MONTH**						
s.dw	1	10	-429.6	890.7	0	0.693
s.dw + s.dr	1	11	-428.4	893.4	2.66	0.183
s.dw + s.dd	1	11	-429.3	895.3	4.60	0.096


Occupancy probability
1.00
0.75
0.50
0.25
0.00
05 06 07 08 09 10 11 12 13 14 15 16 17 18
Year


Occupancy probability
1.00
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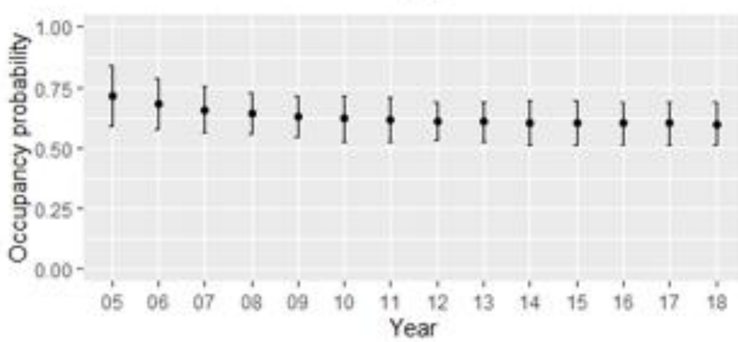
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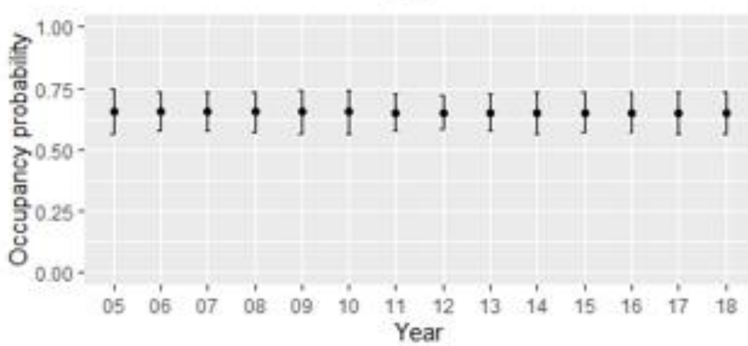
Occupancy probability
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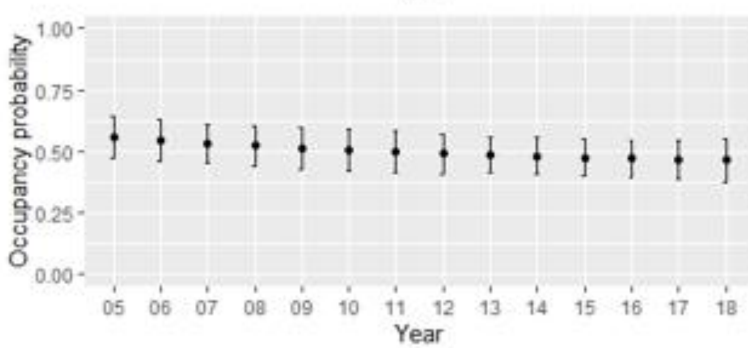
Year


Occupancy probability
1.00
0.75
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0.00
05 06 07 08 09 10 11 12 13 14 15 16 17 18
Year

Species Name	**Detection Probability**	**Colonization (γ) (SE)**	**Extinction (ε) (SE)**
American Bullfrog	0.3176	0.043 ± 0.017	0.056 ± 0.019
American Toad	0.144	0.068 ± 0.058	0.035 ± 0.022
Gray Tree Frog	0.2207	0.166 ± 0.047	0.111 ± 0.0370
Green Frog	0.4628	0.176 ± 0.042	0.094 ± 0.024
Pickerel Frog	0.2760	0.0884 ± 0.026	0.112 ± 0.035