Examining occupancy and detection probability after three years of monitoring for the Illinois chorus frog (*Pseudacris streckeri illinoensis*)

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Executive summary

Illinois chorus frogs (*Pseudacris illinoensis*; "ICF") occur as a genetically distinct population in Illinois and are threatened by the loss of sand prairie habitat and ephemeral wetlands. The Illinois Department of Natural Resources initiated a long-term monitoring plan at 95 sites to track changes in the distribution of ICF. The study design was informed by estimates of occupancy and detection probability based on pilot data from 2011 to 2014. The primary recommendation was to survey 75–90 sites twice each spring. The monitoring plan was initiated in 2015 with 95 sampling locations sampled up to three times each spring. In this report, I examine occupancy data from the first three years of monitoring data to determine if changes in survey design are warranted. I used a multi-season occupancy model to make the following conclusions and recommendations:

- Overall detection probability was 0.60 (95% CI: 0.51 – 0.68), although this estimate does not consider factors that cause variation in detection probability among surveys.

- Detection probability depended strongly on the observer conducting chorus breeding surveys, with observer-specific detection probabilities ranging from 0.11 to 0.77. Observers are assigned to specific routes, and observer variation in detection probability may reflect variation in conditions along routes. I recommend collecting data on traffic and noise during surveys to determine if these conditions explain the observer variation.

- Detection probability depended on multiple aspects of survey conditions, specifically air temperature, humidity, survey date, and wind levels. Surveys should be conducted early in the breeding season and during warm, wet nights with low winds. Data on soil temperature and precipitation may be useful for gaining further insight into why detection probability varies with survey date independently of air temperature during surveys.

- An estimated 61-63% of breeding sites are occupied in the general area of suitable habitat from which sampling locations were selected. This estimate is substantially higher than yearly naïve occupancy not accounting for imperfect detection, illustrating the importance of using rigorous models of detection probability to estimate occupancy.

- Yearly estimates of occupancy probability were remarkably similar. Extinction and colonization probabilities were about 20%, suggesting significant but balanced turnover in breeding populations. Turnover may reflect true extinction and colonization dynamics or temporary emigration in which individuals skip a breeding season.

- Estimates of occupancy, colonization, and extinction probability should be interpreted with caution as they do not account for likely spatial variation associated with habitat quality and land use practices.

- I recommend continuing to survey all sites twice each spring. A third survey should be conducted at sites if detection probability is unusually low during the first two surveys.

1. Introduction

Illinois chorus frogs (*Pseudacris streckeri illinoensis*, hereafter "*P. illinoensis*") occur as isolated populations in Missouri, Arkansas, and west-central and southwestern Illinois (Brown and Rose 1988, Conant and Collins 1991). Phylogeographic evidence based on nuclear and mitochondrial DNA indicates that a historical refugium existed for *P. streckeri/illinoensis* in central Texas, whereas *P. illinoensis* diverged from *P. streckeri* more recently (Barrow et al. 2015). The Integrated Taxonomic Information System currently recognizes *P. illinoensis* as a distinct species.

P. illinoensis occurs in sandy soils found in sand prairies and agricultural fields (Brown and Rose 1998). Adults are terrestrial and migrate to ephemeral, fishless wetlands to breed in early winter and spring. *P. illinoensis* population declines are generally related to the loss and fragmentation of sand prairie habitat and breeding wetlands associated with agriculture (Tucker 1998, Trauth et al. 2006, Illinois Natural History Survey 2017). *P. illinoensis* is listed as "threatened" in Illinois and "rare" in Missouri. The United States Fish and Wildlife Service recently reported there was substantial information that could warrant federal listing of *P. illinoensis* as threatened or endangered, and the species is currently undergoing a status review (Department of the Interior, Fish and Wildlife Service 2015).

In Illinois *P. illinoensis* occurs in sandy soils along the Illinois River corridor as three separate metapopulations. Genetic evidence shows that the northern and southernmost populations are strongly diverged, indicating little ongoing gene flow (Barrow et al. 2015). Most populations on record occur in the northernmost region, and these populations tend to have low genetic diversity, suggesting ongoing declines (Illinois Natural History Survey 2017).

A rangewide pilot study was conducted to examine strategies for long-term monitoring of the *P. illinoensis* distribution in Illinois based on chorus breeding surveys (Hulin et al. 2015). Based on occupancy data from the pilot study, Cosentino (2014) showed that annual sampling of 75-90 sites would lead to high statistical power for detecting 30-50% declines in occupancy over time. In 2015, the Illinois Department of Natural Resources initiated a program to monitor occupancy at 95 locations across the range of suitable habitat for *P. illinoensis* in Illinois.

Hierarchical models to simultaneously estimate occupancy probability and detection probability are essential for obtaining unbiased estimates of occupancy in any given year (MacKenzie et al. 2006). Occupancy models that explicitly account for imperfect detection probability during surveys require repeated surveys at each site within a defined sampling season (MacKenzie et al. 2006). Precise estimates of occupancy probability are needed to infer temporal trends (Guillera-Arroita and Lahoz-Monfort 2012), and precision of occupancy estimates depends on the number of repeated surveys at each site during each season, as well as the magnitude of occupancy and detection estimates (MacKenzie and Royle 2005, Bailey et al. 2007, Guillera-Arroita et al. 2010).

Analysis of pilot data for *P. illinoensis* (Hulin et al. 2015) showed that rangewide occupancy probability was 0.56 (SE = 0.09) and detection probability was 0.77 (SE = 0.05; Cosentino 2014). Based on these estimates, Cosentino (2014) recommended two replicate surveys be conducted at each sampling location during each season when detection probability was high

(>0.7). If detection probability is <0.7, often due to drought conditions, then three replicate surveys were recommended in order to minimize the variance of the occupancy estimator. Cosentino (2014) also recommended recording a variety of environmental variables that could affect detection probability so that variation in detection probability over time and among sites can be adequately modeled.

Analyses of optimal survey effort depend on assumptions about the magnitude of occupancy and detection probability. Here I examine the first three years of occupancy data from the formal monitoring program for *P. illinoensis* in order to determine if occupancy and detection probability estimates are consistent with estimates from the pilot data. Changes in allocation of survey effort would be warranted if occupancy and detection estimates have significantly changed. My specific objectives were to:

1) Estimate the magnitude and precision of occupancy probability in 2015, 2016, and 2017.

2) Estimate the magnitude and precision of detection probability in relationship to date of survey, time of survey, observer identity, number of listening posts and survey conditions including air temperature, humidity, wind, and moonlight.

3) Make recommendations on survey design based on analyses of occupancy and detection probabilities.

2. Methods

2.1. Study area and sampling design

The statistical population of interest for monitoring *P. illinoensis* is suitable habitat within one of three regions: 1) Alexander County (AL), 2) Cass, Morgan, and Scott Counties (CMS), and 3) Mason, Menard and Tazewell Counties (MMT). A GIS-based habitat model was generated for *P. illinoensis* based on the presence of hydric soils, sandy soils, and wetlands for breeding (Hinz et al. 2011, Hulin et al. 2015). Survey sections (2.59 km^2) were randomly selected resulting in 95 sections across the three regions. There were 69 sections in MMT, 16 sections in CMS, and 10 sections in AL.

Each section was surveyed up to three times between March 7 and April 29 in each year, and sections were assumed to be closed to changes in occupancy status within years. Surveys were conducted between 6:00 PM and 1:00 AM. During each survey, observers drove along roads along the perimeter of each section and made multiple stops to listen for chorusing *P. illinoensis* within the section (i.e. “listening posts”). Chorus surveys were conducted for five minute at each listening post. Each survey was conducted by one of nine observers, and the same set of observers conducted surveys in each region (6 observers in MMT, 2 observers in CMS, and 1 observer in AL). Observers recorded the date and time of the survey, number of listening posts at each section, as well as air temperature, humidity, wind level, and moonlight presence during each survey. Wind was recorded on an ordinal scale from 1 (calm) to 5 (fresh breed; >18 mph).

2.2. Occupancy modeling

I used the occupancy data from repeated surveys during each year in a multi-season occupancy model to estimate detection probability, initial occupancy probability in 2015, colonization probability between 2015-2016 and 2016-2017, and extinction probability between 2015-2016 and 2016-2017 (MacKenzie et al. 2003). I then examined a series of multi-season occupancy models to test for effects of date of survey, time of survey, air temperature, humidity, moonlight presence, number of listening posts, wind level, observer, and year on detection probability. Moonlight was classified as present or absent, and number of listening posts was classified as one or >1 post. Julian date was used as a numeric metric of date, and survey time was quantified as number of hours after 6:00 PM. I tested for quadratic effects of survey date, survey time, air temperature, and humidity. I did not include an effect of region on detection probability because of confounding between observer and region. All continuous covariates were standardized before analyses.

I constructed a full model with all covariates of detection included in the model. Initial occupancy probability, colonization probability, and extinction probability were held constant. I used a likelihood ratio test to examine the effect of each covariate on detection probability. I then constructed a reduced model that retained detection covariates that were significant at $P < 0.10$. The reduced model was used to construct plots of predicted detection probability in relationship to covariates. Predictions were made for a single covariate at a time while holding all other covariates at their means. I also used the reduced model to estimate occupancy probability during each of the three survey years based on initial occupancy probability and colonization and extinction probabilities. All occupancy models were fit in R (R Core Team 2017) with the package *unmarked* (Fiske and Chandler 2011).

3. Results and Discussion

P. illinoensis was detected at least once at 56 of 95 sites across the three years (naïve occupancy probability = 0.59). *P. illinoensis* was found at 33 sites in 2015 (naïve occupancy probability = 0.35), 35 sites in 2016 (naïve occupancy probability = 0.37), and 36 sites in 2017 (naïve occupancy probability = 0.38). Not all sections were surveyed during each year. No surveys were conducted at 6 sites in 2015, 21 sites in 2016, and 2 sites in 2017. This variation in survey effort is fully accommodated by a multi-season occupancy model, although efforts should be made to keep the number of unsurveyed sites low in order to maximize precision of parameter estimates.

A multi-season occupancy model with no covariates indicated that initial occupancy probability in 2015 was 0.46 (95% CI: 0.34 – 0.59), colonization probability was 0.20 (95% CI: 0.11 – 0.34), extinction probability was 0.19 (95% CI: 0.09 – 0.36), and detection probability was 0.60 (95% CI: 0.51 – 0.68). The overall detection probability was slightly lower than the detection estimate from the pilot study (0.77), which may have been due to variation in survey conditions or observers. It is notable that the extinction and colonization probabilities were nearly identical, suggesting that the *P. illinoensis* metapopulation was stable between 2015 and 2017. Extinction and colonization probabilities are not necessarily true extinctions and recolonizations. Some turnover dynamics may be caused by a type of temporary emigration in which individuals skip a breeding season.

Detection probability depended strongly on observer and survey conditions. Detection probability was significantly related to air temperature, survey date, humidity, and observer (Table 1). There were also marginally significant effects of number of listening posts and wind level during surveys (Table 1).

Table 1. Likelihood ratio tests for effects of covariates on detection probability based on the full model. Linear effects of covariates were modeled in each case except survey time, which was modeled as a quadratic effect.

Detection covariate	χ^2	*df*	*P*
Air temperature	10.293	1	0.001
Date	4.134	1	0.042
Humidity	12.192	1	<0.001
Listening posts	3.440	1	0.064
Moonlight	0.454	1	0.500
Observer	41.601	8	<0.001
$Time^2$	4.019	2	0.134
Wind	3.233	1	0.072
Year	0.151	2	0.927

The reduced model that included significant effects only (Table 2) showed that detection probability strongly varied among observers (Tables 3, 4), ranging from 0.11 to 0.77. Although there was confounding between observer and region (i.e., observers were each assigned to a single region), there was considerable variation in detection probability among observers assigned to survey sections within MMT and CMS. This variation may be associated with peculiarities of the particular route an observer is assigned to (e.g., traffic and general noise during surveys) or to variation in observer ability. In order to distinguish these hypotheses, I recommend observers 1) collect data on the number of cars that pass by during surveys, 2) record whether or not noise significantly interfered with the observer's ability to hear a chorus (e.g., Cosentino et al. 2014).

Detection probability was greatest in early March and during warm, humid conditions when wind levels were low (Fig. 1). Air temperature and survey date appeared to be the most important survey conditions driving detection probability. It is important to note that although survey date and air temperature are often positively correlated, the magnitude of the correlation was rather low ($r = 0.34$). This suggests that the effect of survey date on detection probability is not simply related to air temperature. The effect of survey date may reflect changing climatic conditions that affect the activity of *P. illinoensis* (e.g., soil temperature, water level in breeding ponds). It may be fruitful to examine the effects of additional climatic variables on detection probability to identify the mechanisms explaining the relationship between detection probability and survey date.

Table 2. Parameter estimates of a reduced model of detection probability with significant effects only based on the full model ($P < 0.10$).

Detection covariate	*b*	*SE*
Air temperature	0.73	0.19
Date	-0.91	0.26
Humidity	0.68	0.22
Listening posts	-0.86	0.43
Observer 1	2.17	0.98
Intercept (Observer 2)	-1.48	0.94
Observer 3	0.27	1.42
Observer 4	-0.14	1.10
Observer 5	3.13	1.03
Observer 6	2.62	1.06
Observer 7	2.68	1.06
Observer 8	0.98	1.03
Observer 9	0.62	0.98
Wind	-0.43	0.19

Table 3. Predicted detection probability for all observers based on the reduced model.

Observer	Detection probability	*SE*	95% *CI*	Region
1	0.11	0.06	0.04 – 0.31	CMS
2	0.13	0.10	0.03 – 0.45	MMT
3	0.16	0.16	0.02 – 0.65	MMT
4	0.22	0.08	0.10 – 0.42	MMT
5	0.28	0.10	0.13 – 0.52	MMT
6	0.57	0.11	0.34 – 0.76	MMT
7	0.67	0.15	0.36 – 0.88	AL
8	0.69	0.14	0.39 – 0.88	MMT
9	0.77	0.10	0.52 – 0.91	CMS

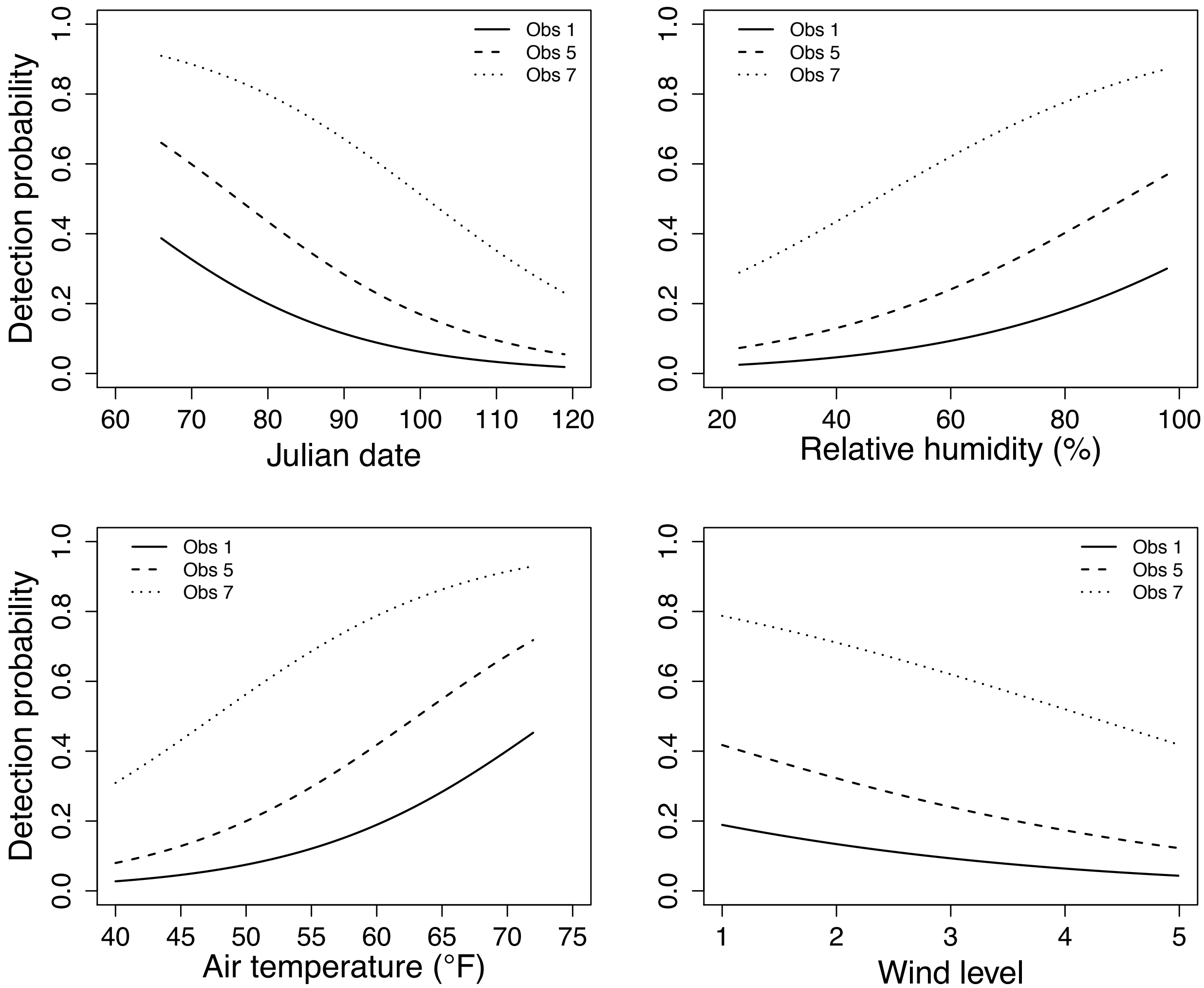

Figure 1. Relationship of detection probability for *P. illinoensis* to Julian date, relative humidity, air temperature, and wind level. Relationships are shown for a subset of three observers with low, medium, and high estimated detection probabilities.

There were marginal effect of wind level and number of listening posts on *P. illinoensis* detection probability. Detection probability was lowest when wind levels were high. Based on these results I do not recommend performing chorus surveys when wind is recorded as a "fresh breeze" (category 5). Curiously detection probability was slightly greater for sections with a single listening post than sections with multiple listening posts (Fig. 2). Sections with more than one listening post may have more roads and traffic than sections with a single listening post. High traffic often leads to low detection probability because of the noise associated with traffic. Alternatively, fragmentation effects may be stronger at sections with high road density, resulting in lower population sizes and thus weaker choruses. Data on noise levels, traffic, and land use variables would provide additional insight into why detection probability was lower at sections with more than one listening post.

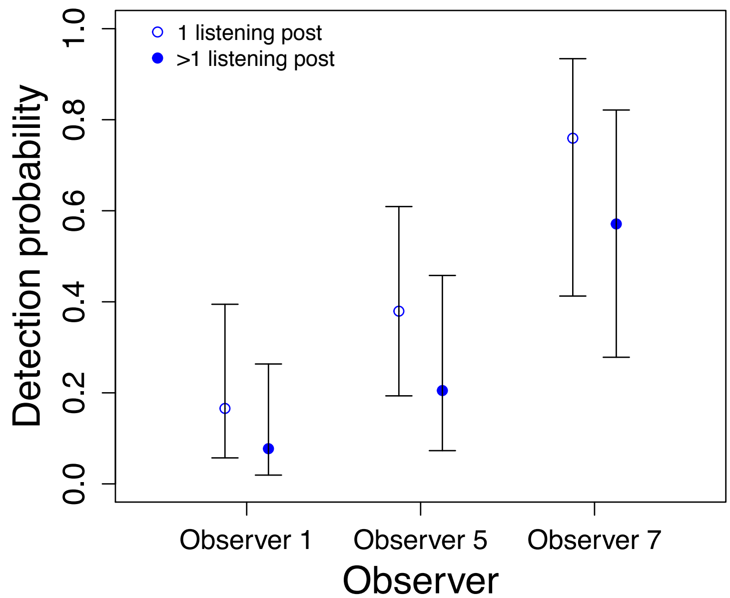

Figure 2. Relationship of detection probability for *P. illinoensis* to the number of listening posts at a section. Relationships are shown for a subset of three observers with low, medium, and high estimated detection probabilities.

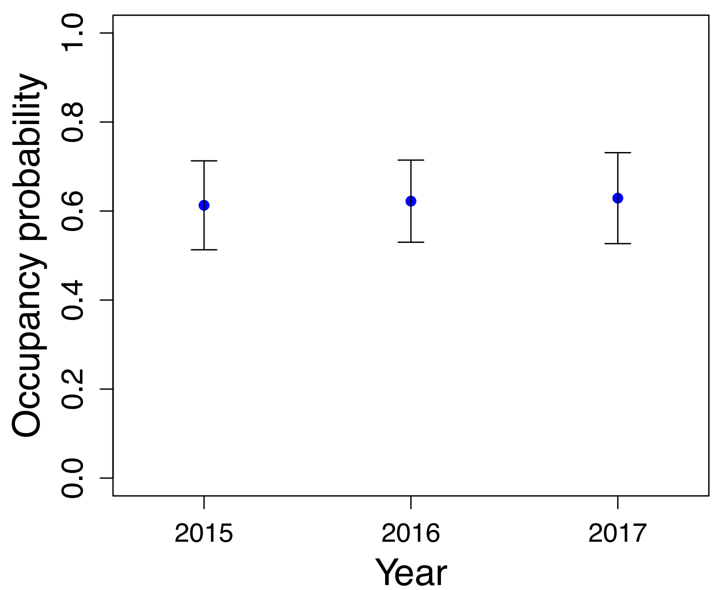

Figure 3. Derived estimates of *P. illinoensis* occupancy probability based on a multi-season occupancy model that accounts for imperfect detection. Error bars represent 1 SE.

I projected occupancy probability across years based on estimates of initial occupancy, colonization probability, and extinction probability using the reduced model with effects of covariates on detection probability. Likelihood ratio tests showed that there was no yearly variation in extinction or colonization probabilities ($P > 0.41$), so a model with static turnover dynamics was adequate. The occupancy projection showed that the best estimate of occupancy probability was around 0.60, and that there was little variation in occupancy probability between 2015 and 2017 (Fig. 3). These derived estimates of occupancy probability are generalizable to the broader population of suitable habitat for *P. illinoensis* from which sections were randomly sampled.

The consistency in occupancy probability estimates over time indicate a stable metapopulation, a pattern that was also observed in the naïve occupancy data. However, it is noteworthy that a more complex model that explicitly considers heterogeneity in detection probability led to occupancy estimates that were nearly double the naïve estimates. One take-home point from this finding is that a robust model of detection probability is essential for obtaining accurate estimates of occupancy probability. Future modeling efforts should also consider spatial variation in occupancy probability and turnover dynamics, particularly soil and land cover variables that are hypothesized to drive variation in population sizes of *P. illinoensis*.

4. Summary of recommendations

4.1. Survey conditions to maximize detection probability

The occupancy models in this report indicate that detection probability can be maximized during surveys by performing surveys early in the breeding season and when temperature and humidity are high and wind speed is low. It may be worthwhile to conduct both surveys on relatively warm, wet (but otherwise calm) nights in March, and data on soil temperature and precipitation may provide further insight into potentially narrow detection windows for *P. illinoensis* chorusing. There was no evidence indicating that detection probability was sensitive to the presence of moonlight or the time when surveys are performed.

4.2. Observer effects on detection probability

A substantial amount of variation in detection probability was explained by the observers performing surveys. Although observer was confounded with region, there was still significant variation in detection probability among observers within region. This may be due to observer abilities to hear chorusing frogs, but it is also possible that routes along which surveys are performed vary in traffic and other types of noise that may interfere with surveys. I recommend that observers collect data on traffic and noise levels during future surveys, which will aid in improving the accuracy and precision of detection probability estimates.

4.3. Survey allocation

My general conclusion is that two surveys per season at each section is adequate for obtaining precise estimates of occupancy probability, turnover dynamics, and detection probability (SE <

0.10). The detection probability estimate based on the 2015-2017 data was slightly lower compared to the estimate based on pilot data (0.60 vs. 0.77). My previous analyses showed that the power to detect declines in occupancy is similar when the number of surveys per site is 2-3 and detection probability is 0.6. An updated power analysis based on the most recent occupancy and detection data bears this out. At the current level of survey effort (average = 172 surveys/year), the power to detect a 30% decline in occupancy is 0.67 with two surveys at each site (assumes the significance level is conservative at 0.20). The power to detect a 30% decline based on the same total effort but three surveys per site is nearly identical (0.69). Conducting two surveys per site becomes more efficient than three as detection probability increases from 0.6. Collectively, I suggest continuing to conduct two surveys per year at each site, with a third survey added if detection probability is perceived to be unusually low or very few detections were recorded across the first two surveys. In years with unusual weather or breeding activity, a removal design can be considered in which surveys are discontinued at a site after *P. illinoensis* is detected. This design allows additional survey effort to be allocated to sites where *P. illinoensis* has not been detected.

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