

Evaluation of the Status of Anurans on a Refuge in Suburban Maryland

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ABSTRACT.—Because many anurans have well-defined breeding seasons and male anurans produce loud advertisement calls, surveys of these breeding choruses are believed to provide a dependable means of monitoring population trends. The Patuxent Research Refuge initiated such a calling survey in the spring of 1997, which uses volunteers to collect anuran (frog and toad) calling survey data. The primary goal of initiating the calling surveys at the Patuxent Refuge was to obtain baseline information on anuran populations, such as species occurrence, frequency of occurrence, and relative abundance over time. In this paper, we used the calling survey data to develop models for the “proportion of area occupied” by individual anuran species, a method in which analysis is focused on the proportion of sites that are occupied by a species, instead of the number of individuals present in the population. This type of analysis is ideal for use in large-scale monitoring programs focused on species that are difficult to count, such as anurans or birds. We considered models for proportion of area occupied that allow for imperfect detection (that is, a species may be present but go undetected during sampling) by incorporating parameters that describe detection probability and the response of detection probability to various environmental and sampling covariates. Our results indicate that anuran populations on the Patuxent Research Refuge have high rates of occupancy compared to areas nearby and that extinction and colonization rates are stable. The potential uses for “proportion of area occupied” analyses are far-reaching and will allow for more accurate quantification of data and better-informed management decisions for calling surveys on a larger scale.

Because many anurans have well-defined breeding seasons and male anurans produce loud advertisement calls, surveys of these breeding choruses are believed to provide a dependable means of monitoring population trends (e.g., Mossman et al., 1998; Corn et al., 2000; Weir et al., 2005). As part of an effort to determine amphibian population changes over time in the United States, a calling survey program, the NAAMP (North American Amphibian Monitoring Program), was established in 1997 and implemented by the USGS Patuxent Wildlife Research Center in Laurel, Maryland. Based loosely on the North American Breeding Bird Survey (Peterjohn, 1994), NAAMP established a unified protocol in 2001 which has since been adopted by at least 31 states and 10 Canadian provinces, with the most extensive monitoring taking place in the northeastern United States (Mossman et al., 1998; Genet and Sargent, 2003; Weir and Mossman, 2005). However, prior to the establishment of the NAAMP unified protocol, the Patuxent Re-

search Refuge (PRR) initiated a calling survey in the spring of 1997. Like NAAMP, the PRR calling survey uses volunteers to collect anuran data. Patuxent Research Refuge is an area of approximately 13,000 acres located in the Patuxent River watershed, nestled at the junction of Prince George’s and Anne Arundel Counties, Maryland. The refuge’s network of vernal pools, permanent ponds and wetlands is extensive and, therefore, is an ideal area to obtain information on amphibian breeding populations. The PRR calling survey focuses on 12 species of frogs and toads commonly encountered in the area. These species are the American Toad (*Bufo americanus*), Fowler’s Toad (*Bufo fowleri*), Northern Cricket Frog (*Acris crepitans*), Gray Treefrog (*Hyla versicolor*), Northern Spring Peeper (*Pseudacris crucifer*), Upland Chorus Frog (*Pseudacris feriarum feriarum*), American Bullfrog (*Rana catesbeiana*), Green Frog (*Rana clamitans*), Wood Frog (*Rana sylvatica*), Southern Leopard Frog (*Rana sphenocphala*), Pickerel Frog (*Rana palustris*), and Eastern Spadefoot Toad (*Scaphiopus holbrookii*). Each species has a unique call that trained observers can distinguish from others and each also generally adheres to a specific breeding period, which makes it possible to differentiate between species and to use call detection as a means to evaluate populations. The calling intensity of each species is recorded as an index of the

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following: one = individuals can be counted, and there is space between calls; two = calls of individuals can be distinguished, but calls are overlapping; three = full chorus, calls are constant, continuous, and overlapping (Mossman et al., 1998; Crouch and Paton, 2002; Stevens et al., 2002; Weir and Mossman, 2005). The primary goal of initiating the calling surveys at PRR was to obtain baseline information on anuran populations, such as species occurrence, frequency of occurrence, and relative abundance over time. The goals of this study are to conduct a preliminary analysis of PRR survey data and to evaluate the protocol to make it more efficient for future surveys.

In this paper, we develop models of site-occupancy, or the "proportion of area occupied" (PAO), by various anuran species. We focus on PAO as a metric of population status because it is difficult to relate calling index data, a numerical representation of the calling levels of anurans, to a more precise description of population status. Conversely, PAO may be estimated based on observations of presence/absence at sample locations. In effect, the PAO framework shifts the focus of the analysis from numbers of individuals in the population to the number of sample units occupied by these animals (MacKenzie et al., 2002; Royle and Nichols, 2003). An explicit focus on PAO is ideal for use in large-scale monitoring programs focused on species, such as anurans, that are difficult to count, and is regarded as an important descriptor of metapopulation state (Hanski and Gilpin, 1997).

The PRR calling surveys use a sampling design that allows for explicit consideration of detection probability using the methods described by MacKenzie et al. (2002). These methods specifically address the problem of "false absences" in observational survey data. That is, a putative absence at a particular sampling location may be in error when species are detected imperfectly and, thus, apparent site occupancy rates (the number of sites observed to be occupied) will be negatively biased in most practical problems. In contrast, methods which do not account for imperfect detection lead to biased estimates of site occupancy and biased estimates of the effect of factors that influence species occurrence (Hirzel et al., 2002; Moilanen, 2002; Anderson, 2003; Weir et al., 2005). Another benefit of a PAO model is that it does not require assumptions to be made about functional relationships between patch-specific extinction probabilities and patch characteristics, or between patch-specific colonization rates and isolation. Instead, these types of relationships are evaluated formally in the model,

allowing for a more objective evaluation of the data (MacKenzie et al., 2003).

MATERIALS AND METHODS

Since the spring of 1997, the PRR calling survey has been conducted at 47 established points along refuge roads and trails. The sites chosen are a subset of the PRR wetlands and can be classified as ponds, marshes, wet meadows, shrub swamps, or forested wetlands. Some (14.89%) of the pools included in the survey area are created by spring floods and are temporary, or "vernal," and these are preferentially used by certain amphibian species (*R. sylvatica* and *Pseudacris feriarum*) for breeding. These vernal pools do not contain predators such as fish or larger amphibians such as *R. clamitans* and *R. catesbeiana*, which would have a negative effect on recruitment (Calhoun et al., 2003). However, the majority of the pools and ponds surveyed in the PRR calling study are permanent (48.94%) or semipermanent impoundments (36.17%), created between 1945 and 1963 primarily for the purpose of studying wetland vegetation and to create habitat for waterfowl. These 140 ha of impoundments are of three major designs: dammed ravines, excavated basins, and diked ponds (Perry et al., 1997). Many of these water bodies contain fish such as Large-Mouth Bass (*Micropterus salmoides*) and Bluegill (*Lepomis macrochirus*; H. H. Obrecht, pers. comm.).

We restricted our analysis to the six species (Table 1) with the greatest number of observations, to ensure adequate sample size. We included a representative from most anuran families on the refuge, and therefore, results should reflect the wide array of breeding preferences and behaviors exhibited by anurans in this area. Two representatives were selected from Ranidae because of the prevalence of this family among surveyed species.

The PRR calling surveys are conducted once every two weeks from early spring through midsummer. Survey methods followed NAAMP unified protocol (Weir and Mossman, 2005). Observers (trained volunteers) record a calling index at between five and 10 sites per night. Surveys begin 30 min after sunset and are not performed in rain or when the wind is greater than a 3 on the Beaufort scale. From 1997–2000, observers stopped at each site and listened at the designated area for 3 min. This protocol was revised to a 5-min listening period in 2001 in accordance with the NAAMP unified protocol. However, because of concern that data from the earlier years (1997–2000) would not be comparable to the new 5-min period, observers continue to record indices after 3 min, which

TABLE 1. Total number of sampling occasions that each anuran species was observed (per year) during calling surveys at the Patuxent Research Refuge (1997–2003).

Species	1997	1998	1999	2000	2001	2002	2003	Total
<i>A. crepitans</i>	235	287	232	259	256	247	116	1632
<i>B. americanus</i>	50	26	30	23	29	44	39	241
<i>B. fowleri</i>	66	110	50	70	67	35	36	434
<i>H. versicolor</i>	121	163	87	174	137	121	105	908
<i>P. crucifer</i>	175	135	196	192	182	180	126	1186
<i>P. feriarum feriarum</i>	-	-	6	22	10	8	1	47
<i>R. catesbeiana</i>	165	178	131	209	175	156	86	1100
<i>R. clamitans</i>	277	311	216	304	291	271	97	1767
<i>R. palustris</i>	103	90	82	118	75	70	68	606
<i>R. sphenoccephala</i>	123	106	127	153	132	155	114	910
<i>R. sylvatica</i>	-	-	12	10	8	24	3	57

results in two values being recorded for each species at each site. Each site has a specified listening arc of either 90°, 180°, 270°, or 360°, depending on its proximity to other sites. For our purposes of developing PAO models of anuran metapopulation status, the data were reduced to binary detection/nondetection (1,0). Converting index values to binary data avoids the problem of having differing interpretations of calling index values, an issue particularly evident between the indices of two and three (Bishop et al., 1997; Shirose et al., 1997).

Statistical Models.—PAO models (MacKenzie et al., 2002) can easily be extended to multi-season data (MacKenzie et al., 2003). Multi-season models allow for changes in the occupancy status of sites across years by including additional parameters to describe local extinction and colonization events. Multiseason models are parameterized in terms of an initial site-occupancy rate parameter ψ and local extinction and colonization parameters (ϵ , γ), respectively. We refer the interested reader to Mackenzie et al. (2002, 2003) for further details. An alternative formulation of the models can be found in J. A. Royle and Kery (2007) who adopt a state-space formulation of the model. We used the software package PRESENCE (available at www.mbr-pwrc.usgs.gov/software.html) to fit the PAO models described in this paper by the method of maximum likelihood.

In the development of PAO models, we considered several sampling covariates thought to influence detectability of anurans: air temperature (taken at each sampling point, herein referred to as temperature), date, and time. Sunset times for the years of 1997 through 2003 were obtained from the U.S. Naval Observatory (http://aa.usno.navy.mil/cgi-bin/aa_rstblew.pl). "Date" of survey was included to evaluate the influence of seasonal variation. Survey dates were converted to Julian dates. These covariates were modeled as being linear on the logit

probability scale. That is, let p_{ijt} be the detection probability at site i , day j , and year t . Then, a linear relationship was assumed between $\log(p_{ijt}/(1 - p_{ijt}))$ and any covariates under consideration. Additional technical details can be found in MacKenzie et al. (2003, 2005).

Model Selection.—We considered the following multiseason models: (a) extinction, colonization, and detection constant; (b) constant extinction and colonization but variable detection; (c) constant detection but variable extinction and colonization; and (d) extinction, colonization, and detection variable. Conventional model selection procedures based on AIC (Akaike's Information Criterion) were used to select among models under consideration. In our analyses, we used the AIC adjustment for small sample sizes (AIC_c; Burnham and Anderson, 2002).

Considering the possibility that available covariates influence detection probability, the model set consisting of models (a)–(d) with and without all possible covariates yields an enormous model set for which evaluation of every model would be impractical. Thus, we carried out the model fitting in two stages. First, we selected the best model (according to AIC) without covariates from among the four models (a)–(d). In Stage two, this model was extended by considering addition of the covariates Julian date (season), temperature, and time-after-sunset. All three factors were found to be important in anuran calling survey data of Maryland (Weir et al., 2005), based on a priori hypotheses regarding factors that influence anuran behavior. Following Weir et al. (2005), we considered the possibility that such effects might be quadratic but considered the reduced, linear effect in both cases because the quadratic effect might be sufficiently well approximated by a linear effect over the period of time over which data were collected. The model set is summarized in Table 2.

TABLE 2. Two-step selection of detection and occupancy probability models for six anuran species observed during annual calling surveys conducted over seven years at the Patuxent Research Reserve. Step 1 was performed without covariates to determine whether extinction, colonization, and detection were constant or variable for each species. Step 2 incorporated the additional effects of temperature, time after sunset, and season as either linear (L) or quadratic (Q) terms. Parameters included in each model are indicated by dots. AICc values are given for each species for each model. Lower values of AICc indicate increased parsimony; * indicates the most parsimonious model(s) for a species.

Step 1 model selection (no covariates)											
Species						Parameter combination					
						Extinction/ Colonization		Detection			
						Constant	Variable	Constant	Variable		
<i>A. crepitans</i>	<i>B. fowleri</i>	<i>H. versicolor</i>	<i>P. crucifer</i>	<i>R. clamitans</i>	<i>R. sphenoccephala</i>						
5134.4	2658.9	4147.4	4710.1	5192.5	4161.6	•		•			
5147.5	2663.7	4149.7	4724.8	5207.2	4181.4		•	•			
5127.8	2648.6	4083.1	4700.5	5150.3	4157.0		•		•		
5105.6*	2612.7*	4060.3*	4675.7*	5126.9*	4123.6*	•			•		
Step 2 model selection (constant extinction and extinction, variable detection)											
Species						Parameter combination					
						Temperature		Season		Sunset	
						L	Q	L	Q	L	Q
<i>A. crepitans</i>	<i>B. fowleri</i>	<i>H. versicolor</i>	<i>P. crucifer</i>	<i>R. clamitans</i>	<i>R. sphenoccephala</i>						
4210.4	2479.4	3651.5	3764.5	4165.3	3737.4	•					
4094.2	2441.3	3572.0	3438.7	4064.9	3526.0	•	•				
4625.9	2611.9	3935.7	2918.2	4056.8	3467.3			•			
2132.1	2249.4	3216.9	2252.9	3526.8	3348.8			•	•		
5059.8	2574.1	4035.2	4664.3	5132.2	4116.0					•	•
5062.5	2582.1	4033.8	4661.2	5129.2	4115.4					•	
4212.8	2393.1	3627.9	2889.7	3972.2	3469.6	•		•			
4092.7	2336.9	3533.1	2603.8	3892.8	3295.1	•	•	•			
3078.9	2161.0	3148.9	2205.0	3528.4	3351.8	•		•	•		
3069.9	2150.5	3132.7*	2179.9	3519.3	3262.7	•	•	•	•		
3068.7	2137.0*	3137.9	2173.2	3517.3	3248.3*	•	•	•	•	•	•
3067.3*	2146.8	3135.1	2171.4*	3515.3*	3248.1*	•	•	•	•	•	•

RESULTS

The results from the analysis were nearly uniform across species. The best model for all six species had constant colonization and extinction, and variable detection probability (Table 2). Extending this model by the inclusion of the three covariates—Julian date, temperature, and time-after-sunset—also resulted in identical best-fit models for four of the six anurans (Table 2). The best fit model for all six species included quadratic and linear terms for Julian date and temperature (Fig. 1). *Pseudacris crucifer*, *R. sphenoccephala*, *R. clamitans*, and *A. crepitans* all have a linear relationship with sunset. *Rana sphenoccephala* had a nearly identical AICc for sunset expressed as a linear and as a quadratic effect. *Bufo fowleri* had a slightly lower AICc when sunset was expressed as a quadratic effect as opposed to the linear relationship. *Hyla versicolor* had a slightly lower AICc when sunset was not included as a covariate. Estimated detection probabilities can be found in Table 3. Model coefficients are given in Table 4.

Occupancy probabilities were greater than 0.90 for all species except *H. versicolor* (Table 5). Although the variation in detection probability was sizeable (Fig. 1), species that were detected relatively infrequently (e.g., *R. sphenoccephala*) had occupancy rates as high as those detected easily (e.g., *A. crepitans*; refer to Tables 2, 4). The extinction probability for all species was extremely low, although *B. fowleri* had a higher extinction probability than the other species with a maximum value of 0.13. Overall, these six anurans had a very low average extinction rate of 0.05. Colonization probabilities were more variable, ranging from a low of 0.31 for *B. fowleri* to a high (maximum possible) of 1.00 for *P. crucifer*. Because colonization and extinction rates were determined to be constant, it was possible to summarize metapopulation status by calculating the equilibrium occupancy rate (Levins, 1969):

$$\Psi_{eq} = \gamma / (\gamma + \varepsilon) \quad (1)$$

Where γ = colonization probability, and ε = extinction probability. In the case of PRR, the

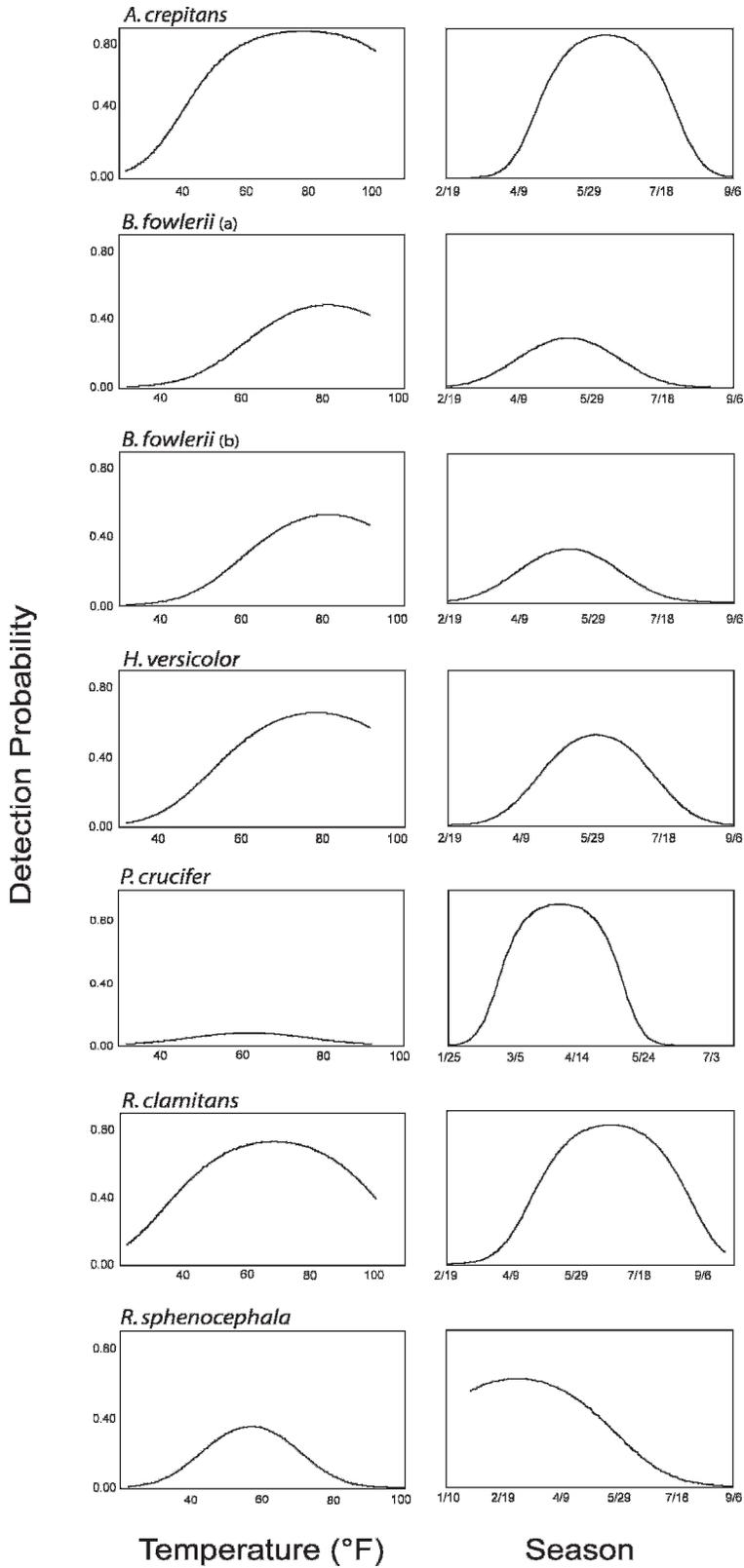


TABLE 3. Estimates of detection probability for six anuran species observed during calling surveys at the Patuxent Research Reserve (1997–2003). Values are an inverse-logit of the estimated intercept parameter from the most parsimonious occupancy model including covariates.

Year	<i>A. crepitans</i>	<i>B. fowleri</i>	<i>H. versicolor</i>	<i>P. crucifer</i>	<i>R. clamitans</i>	<i>R. sphenoccephala</i>
1997	0.8207	0.2377	0.5060	0.0669	0.7787	0.3083
1998	0.9215	0.4671	0.6398	0.0414	0.8657	0.2580
1999	0.7286	0.2053	0.2848	0.0725	0.5542	0.2542
2000	0.7600	0.2677	0.5179	0.0668	0.7026	0.3365
2001	0.7839	0.2713	0.4378	0.0873	0.7290	0.3190
2002	0.7382	0.1607	0.3719	0.0595	0.6451	0.3025
2003	0.8973	0.3947	0.7913	0.2236	0.6636	0.5606

occupancy state distributions of *R. clamitans*, *A. crepitans*, *P. crucifer*, and *R. catesbeiana* are similar to the equilibrium value, whereas *H. versicolor* occupancy is lower than the equilibrium (0.77 vs. 0.95), and *B. fowleri* current occupancy is higher than equilibrium (0.95 vs. 0.71; Table 5).

DISCUSSION

Status of Anuran Populations on Patuxent.—Overall, the occupancy rates for species at PRR were higher than those found in the NAAMP study also conducted in Maryland, presumably because the PRR survey was conducted exclusively on protected land. For example, the occupancy rates for *H. versicolor* and *R. clamitans* in the NAAMP study were 0.48 and 0.63, respectively (Weir et al., 2005), whereas the best-fit multiyear models from the PRR study found occupancy rates of 0.95 and 0.96 for these species. Despite the high turnover in breeding site use, represented by the constant colonization and extinction rates, occupancy rates were consistently high for all species. The availability of multiple ideal breeding sites on the refuge allows for individual anurans to utilize more than one site across a number of years, which may contribute to the overall stability of the population. The six species analyzed were at or near equilibrium occupancy (current occupancy was near or equal to ψ_{eq}).

Occupancy levels for some of the species evaluated in the NAAMP study conducted in eastern Maryland (Weir et al., 2005) and detection levels from a similar study done in Rhode Island (Crouch and Paton, 2002) were similar to results from PRR. Although the

Rhode Island study did not use a site-occupancy model, they found that Spring Peepers (*P. crucifer*) were detected on over 90% of surveys during their peak sampling period (Crouch and Paton, 2002). A similar study conducted on Prince Edward Island in Canada found *P. crucifer* to be present on 88% of reference sites (Stevens et al., 2002). Another species, *R. clamitans*, which had both high occupancy and detection at PRR, was also found to occupy a large number of sites in both the NAAMP study and the Rhode Island study, having the second highest occupancy of all species in the NAAMP study and being detected at 88% of sites in Rhode Island (Crouch and Paton, 2002; Weir et al., 2005). These examples illustrate the compatibility of these species' detection levels and patterns of behavior with calling survey methodology. In contrast, the low detection probabilities of *B. americanus* and *R. sphenoccephala* suggest that a different survey method may be necessary to detect these species at higher numbers, although the site-occupancy model that factors in detection probability does mitigate this concern to a degree.

Detection Probability and Design.—Strong seasonal structure in detection probability as a result of breeding behavior was found for all species. Peak detection of each species is consistent with expected patterns, that is, *P. crucifer* and *R. sphenoccephala* begin breeding early in the spring, whereas species such as *R. clamitans* and *H. versicolor* peak later in the season when temperatures have warmed. *Pseudacris crucifer* had a high detection probability correlated with season but a surprisingly minimal relationship with temperature. Although all species exhibited expected relationships with

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FIG. 1. Detection probability as a function of air temperature (left panels) and season (right panels) for six anuran species observed during calling surveys on the Patuxent Research Reserve from 1997–2003. Detection curves reflect most parsimonious model as determined by AICc. For *Bufo fowleri*, models with linear or quadratic terms for season were equally parsimonious; both are presented. Note that X and Y axes vary between species.

TABLE 4. Estimated values of linear and quadratic² coefficients for covariates included in the most parsimonious models of detection and occupancy probability for six anuran species observed during calling surveys on the Patuxent Research Reserve (1997–2003).

Species	Covariate				
	Temp	Temp ²	Season	Season ²	Sunset
<i>A. crepitans</i>	0.65	-0.23	1.48	-2.18	-0.12
<i>B. fowleri</i>	1.09	-0.33	-0.53	-1.34	-0.19
<i>H. versicolor</i>	0.83	-0.30	0.54	-1.45	-0.06
<i>P. crucifer</i>	0.004	-0.39	-9.06	-4.33	-0.21
<i>R. clamitans</i>	0.23	-0.20	1.65	-1.22	0.12
<i>R. sphenoccephala</i>	-0.45	-0.54	-1.41	-0.42	0.20

season and temperature, for *H. versicolor* and *B. fowleri* the relationship between detection and temperature appeared to be stronger than that between detection and season. For *A. crepitans*, these two factors were of equal importance, whereas for *R. clamitans*, *R. sphenoccephala*, and *P. crucifer*, season appeared marginally more important. The abbreviated breeding period of *P. crucifer* contrasted drastically with the more extended calling of *R. sphenoccephala* and *R. clamitans*.

The variation in estimated base-line detection probabilities (that is, the inverse-logit of the estimated intercept of the detection probability model) among years (Table 3) may be explained by the amount of rainfall, particularly with *R. clamitans*, *H. versicolor*, and *B. fowleri* in 1999, a dry year. The 2003 surge in detection for many species coincides with the unusually heavy rains of that survey season. Another study, done in Wisconsin, found that *R. clamitans* trends were highly correlated with drought conditions (Mossman et al., 1998), as exhibited by this species on PRR. There is also some evidence that *H. versicolor* is detected more often during rainy periods (Bishop et al., 1997). This suggests that it may be necessary in future modeling efforts to include rainfall as a covariate to better mitigate the impact extreme precipita-

tion conditions may have on anuran detection and occupancy. Rainfall recency should be documented by observers during future surveys so this information is available for analysis.

There were numerous similarities between the findings from the PRR calling survey analysis and findings from previous studies, particularly another study conducted in eastern Maryland by NAAMP (Weir et al., 2005). As expected, temperature and season were found to be the most important factors in determining an anuran's calling period (Mossman et al., 1998; Weir et al., 2005), because these quadratic covariates were included in the best-fit model for all species. Four of the six species included in our study (*B. fowleri*, *P. crucifer*, *H. versicolor*, *R. sphenoccephala*) also had a quadratic relationship with temperature in Weir et al. (2005). Interestingly, Weir et al. (2005) did not find a quadratic relationship with temperature for *R. clamitans* because of their use of a smaller temperature range, and they did not include *A. crepitans* in their analysis. In line with our findings, Weir et al. (2005) found that the linear relationship with time from sunset was positive for *R. clamitans*, which implies that detection increases from sunset. We also found a positive linear relationship with time from sunset for *R. sphenoccephala*, the other ranid analyzed, al-

TABLE 5. Metapopulation parameters estimated from the most parsimonious models (with covariates included) of occupancy and detection probability for six anuran species observed during calling surveys on the Patuxent Research Reserve (1997–2003). Occupancy indicates the current estimate; ψ_{eq} represents the equilibrium occupancy rate calculated from estimated rates of colonization and extinction. For *Bufo fowleri*, models with linear and quadratic terms for the sunset covariate were equally parsimonious; therefore, both are presented.

Species	Occupancy	Colonization	Extinction	ψ_{eq}
<i>A. crepitans</i>	0.91	0.63	0.03	0.95
<i>B. fowleri</i> (linear sunset)	0.95	0.31	0.13	0.71
<i>B. fowleri</i> (quadratic sunset)	0.95	0.32	0.12	0.73
<i>H. versicolor</i>	0.77	0.69	0.04	0.95
<i>P. crucifer</i>	1.00	1.00	0.02	0.98
<i>R. clamitans</i>	0.93	0.82	0.03	0.96
<i>R. sphenoccephala</i>	0.91	0.50	0.04	0.93

though Weir et al. (2005) did not. All other species at PRR had a negative linear relationship with time from sunset, except for *B. fowleri*, which demonstrated a quadratic relationship. This indicates that in addition to having a peak calling temperature and season, *B. fowleri* has a definable peak calling time as well. The effects we have found regarding season and temperature windows should be used to inform survey study design. However, further study will be necessary to determine how these findings on the relationship between anuran calling and time-after-sunset should contribute to protocol changes at specific locations.

For future surveys, it may be beneficial to increase the number of sites surveyed to include ponds that are more likely to attract species that often go undetected (i.e., temporary pools used by *R. sylvatica*). It also may not be necessary to survey sites every two weeks as has been done in the past. "Sampling windows" based on peaks in detection (Fig. 1), similar to those currently used by NAAMP, would ensure that sampling encompasses the breeding activity of all species (Weir and Mossman, 2005; Weir et al., 2005), while also allowing for a reduction in overall effort.

Limitations.—One important limitation of site-occupancy models is that they are based on a reduction of the observed index data to binary values, thus potentially leading to a loss of information if the index values are related to abundance. Recently, Royle (2004; see also Royle and Link, 2005) suggested a generalization of site-occupancy models that makes use of the observed index data rather than reducing index values to binary observations of detection/nondetection. A model that incorporates index values may allow for a higher degree of sensitivity to variance between sites when evaluating species with extremely high occupancy, as was the case at PRR. Approaches such as these may provide for a more efficient use of calling index data in future analyses.

Although other studies have found problems with using index values for analysis because of differing interpretation of these values, especially between calling indices two and three (Genet and Sargent, 1997; Mossman et al., 1998); the incorporation of observer ability into such a model could minimize such variation and, in turn, increase the accuracy of occupancy estimates. This could potentially be accomplished through using the NAAMP Frog Quiz (Weir et al., 2005), which evaluates the level of auditory ability in an objective manner.

Although manual call surveys have been found to be an adequate method for monitoring anurans (e.g., Mossman et al., 1998; Corn et al., 2000; Weir et al., 2005), there are a handful of species that will always be difficult to detect

when using this technique. The anurans that were either not detected or detected infrequently at PRR, such as *S. holbrookii*, *R. palustris*, *B. americanus*, *R. catesbeiana*, and *R. sylvatica*, have been overlooked in other calling surveys as well (Bridges and Dorcas, 2000; Crouch and Paton, 2002). Egg mass counts (Grant et al., 2005), transects, or targeted surveys may need to be established in known areas of occurrence because these anurans may be overlooked during calling surveys and may require more intensive methods to ensure proper monitoring (Bishop et al., 1997; Crouch and Paton, 2002).

Conservation Implications.—Occupancy levels are higher on the refuge than in nearby Maryland (for most species), and colonization/extinction rates are generally constant. This highlights the need for the continued protection of lands already set aside for wildlife and the acquisition of additional protected natural spaces, because it is apparent from these results that, when land is set aside and managed properly, amphibians and presumably other fauna benefit immensely, regardless of heavy developmental pressures nearby.

Calling surveys have great value in promoting the concept of conservation and allowing local citizens to take part in the protection of irreplaceable ecosystems and, therefore, have the unique quality of benefiting both the people of a community and the natural areas contained within. Although there are limitations to the number of sites and types of amphibians that can be monitored with such a survey, this technique is a cost-effective and efficient way to monitor anurans. The establishment of such surveys at additional refuges, sanctuaries, and parks will help to ensure continued monitoring of amphibians and, in turn, the collective health of the surrounding ecosystem.

Acknowledgments.—We would like to thank J. Eastridge, R. Burley, H. Obrecht, J. Hines, and especially R. Jung-Brown for their assistance and advice and W. White for editing suggestions. We also acknowledge and thank the calling survey volunteers for their many hours of work and their continued dedication to research at Patuxent.

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Accepted: 19 September 2006.