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## DIFFERENCE IN DETECTION AND OCCUPANCY BETWEEN TWO ANURANS: THE IMPORTANCE OF SPECIES-SPECIFIC MONITORING

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**Abstract.**—Amphibians are declining and require improved monitoring to overcome data deficiency and to improve population estimation. To improve monitoring of two anurans in the prairie province of Alberta, Canada, we conducted repeat daytime surveys at 68 aquatic sites across 90,000 km<sup>2</sup>. We used single- and multi-season occupancy models to evaluate covariates of detection probability ( $p$ ) for Northern Leopard Frogs (*Lithobates pipiens*) and Boreal Chorus Frogs (*Pseudacris maculata*). Single surveys did not perform well in any season for either species. The principal method for detecting Northern Leopard Frogs was visual sightings in summer; Boreal Chorus Frogs were best detected by their breeding calls in spring. Northern Leopard Frog's  $p$  correlated with temperature (+) and wind (–) and was highest in summer. Boreal Chorus Frog probability of detection correlated with temperature (+), observer (–), and visual obstruction (–), and was highest in spring. Therefore, daytime surveys will be more effective for Northern Leopard Frogs in summer and for Boreal Chorus Frogs in spring. Whereas multi-species surveys often yield important information on amphibians, our study suggests species-specific surveys that quantify and maximize detection probability can improve the collection of data for conservation of threatened species.

**Key words.**—anuran monitoring; imperfect detection; *Lithobates pipiens*; *Pseudacris maculata*; occupancy modeling

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### INTRODUCTION

Since 1980, 122 amphibian species have become extinct and many more are endangered (McCallum 2007). This extinction rate is much greater than estimates of natural extinction rates (McCallum 2007). However, some evidence for amphibian declines is anecdotal. Improved monitoring methods are needed to accurately estimate species' status and the level of management necessary to halt declines (Weir et al. 2009). These improvements are also required to overcome data deficiency, reduce bias, and increase accuracy of population parameter estimates (Biek et al. 2002).

Substantial effort has gone into developing multi-species amphibian monitoring protocols (e.g., North American Amphibian Monitoring Program, National Amphibian and Reptile Recording Scheme; Weir et al. 2005, 2009; Sewell et al. 2010), which help in understanding long-term amphibian trends on regional and national scales. However, species-specific monitoring approaches are also necessary for species that are data-deficient or at risk of extinction and require specific management actions.

Many anurans associate with standing water, so their populations are often patchily-distributed across the landscape. Whether these populations function as

metapopulations is often unclear (Marsh and Trenham 2001; Smith and Green 2005). An abundance estimate is often unattainable as a metric for monitoring population status due to its variability and the work involved in collecting the data at each patch. Documenting patch (site) occupancy is a more practical option because it can be measured using presence/absence surveys, utilizing each site as a sampling unit. However, patch occupancy (like abundance) can be negatively-biased when the probability of detecting the species is  $< 1$  (MacKenzie et al. 2002).

Models recently developed for estimating occupancy account for imperfect detection by using data from repeat surveys (MacKenzie et al. 2002; Tyre et al. 2003). Nonetheless, many researchers continue to conduct single surveys, particularly when funding is limited and there is a need to work at large spatial scales. Estimating probability of detection ( $p$ ) and incorporating it into the modeling process can reduce bias, but if  $p$  is small, then imprecision may still be high (MacKenzie et al. 2006). In addition to having an adequate numbers of secondary sampling occasions, precision will be improved if variables correlated with  $p$  are identified prior to establishing monitoring programs and if subsequent surveys only occur when  $p$  is high.

Nighttime call surveys are commonly used for anurans but problems with this method include: imperfect

detection associated with timing and weather conditions, error in identification, and inter-observer variability (Bridges and Dorcas 2000; de Solla et al. 2005; Lotz and Allen 2007). Daytime visual surveys are an alternative (Paszukowski et al. 2002; Vonesh et al. 2010), which might be easier for small professional teams to implement on large scales in the absence of an intensively-coordinated volunteer program. Daytime visual surveys are the typical way that professional wildlife managers or consultants survey anurans in the prairies of Canada for empirical research or prior to industrial developments (e.g., Browne et al. 2009). Daytime visual surveys may face the same problems as nighttime call surveys, but this is poorly studied.

We studied Northern Leopard Frogs (*Lithobates pipiens*) and Boreal Chorus Frogs (*Pseudacris maculata*) in Alberta, Canada to understand their detectability and improve monitoring. These species often co-occur in wetlands across the Canadian prairies (Russell and Bauer 2000). Northern Leopard Frogs are large (up to 11 cm snout-vent length [SVL]) and, although common in much of the species' range, they are classified as 'threatened' in many states and provinces in the Pacific Northwest including Alberta (COSEWIC 2009). In British Columbia, they are considered 'endangered' under British Columbia's Wildlife Act. Boreal Chorus Frogs are small frogs (up to 3 cm SVL) and are considered of 'low priority' for conservation in Canada (Committee on the Status of Endangered Wildlife in Canada. 2012. Candidate Wildlife Species. Available from [http://www.cosewic.gc.ca/eng/sct3/index\\_e.cfm#1](http://www.cosewic.gc.ca/eng/sct3/index_e.cfm#1)) [Accessed January 2013] as they are likely not at risk. Northern Leopard Frogs typically lay eggs in fishless, shallow, warm water with pH > 6 and sufficient dissolved oxygen in temporary or permanent wetlands such as lakes, wet meadows, ponds, and marshes (Merrell 1977; Schlichter 1981; Corn and Livo 1989; Gilbert et al. 1994; Sparling 2010). They over-winter under the ice in well-oxygenated water and emerge in the spring to breed (Emery et al. 1972; Cunjak 1986), whereas Boreal Chorus Frogs over-winter in terrestrial habitats (Russell and Bauer 2000). Metamorphosis occurs during the summer in both species.

Our objectives were to: (1) quantify the level of bias in estimates of occupancy derived from single surveys of Northern Leopard Frogs and Boreal Chorus Frogs; (2) identify variables that affect probability of frog detection; (3) determine if occupancy is highest in spring or summer, and if this differs between the two species; and (4) assess the practicality of surveying the two species together, or if there would be an advantage in species-specific monitoring.

## MATERIALS AND METHODS

**Study site.**—This research involved surveys of 68 wetlands within a 90,000 km<sup>2</sup> area of southern Alberta (Fig. 1). Our study area was bounded by Cypress Hills in the east, Porcupine Hills in the west, Drumheller in the north, and Lethbridge in the south. This area is predominantly in the prairie grasslands ecozone (Shorthouse 2010). We selected wetlands within four major river basins: Bow River, Red Deer River, South Saskatchewan River, and Oldman River. Our study sites included ponds, beaver dams, lakes, streams and their backwaters, slow-moving parts of rivers, sloughs, canals, and gravel extraction pits.

**Sample size determination.**—To determine the optimal number of sites and surveys we undertook power calculations using the equations in MacKenzie et al. (2006). The calculations used occupancy ( $\psi$ ) values of 0.4 and 0.2 taken from the 2000–2001 and 2005 Alberta provincial survey results for Northern Leopard Frogs (Kendell 2002; Kendell et al. 2007). The calculations were repeated across a range of detection probabilities ( $p$ ), with  $p = 0.5, 0.4,$  and  $0.2$  representing low detection in spring and  $p = 0.8, 0.7,$  and  $0.5$  representing higher detection in late-summer when young-of-the-year are available. The calculations (Appendix 1) indicated several possible designs. We chose to survey 70 sites four times, because the calculations suggested that this should typically allow for a standard error (SE)  $\leq 0.07$  on estimates when occupancy is around 40%. Achieving a SE  $\leq 0.05$  when occupancy is around 40% would have been desirable, but would require surveying > 100 sites, which was impractical given our resources.

**Site selection.**—We selected 70 sites from ~300 potential sites in our study area, using a stratified random design, with each of the habitat categories (mentioned below) proportionally represented. We selected sites based on their suitability as Northern Leopard Frog habitat because they are an "at risk" species and data are needed for their conservation. However, on the prairies of Canada, as with other parts of North America, Northern Leopard Frogs and Boreal Chorus Frogs are known to coexist (Quinlan et al. 2003; Russell and Bauer 2000), so we were also able to collect data on Boreal Chorus Frogs. Potential sites were partitioned into four types: (1) sites where Northern Leopard Frogs were observed in a 2005 census; (2) sites where Northern Leopard Frogs were observed during *ad hoc* surveys in 2006–2008 (Alberta Fish and Wildlife Division, unpublished data); (3) sites predicted by models to have high quality Northern Leopard Frog habitat, but with no recorded surveys (Stevens et al. 2010); and (4) sites predicted by models to have medium

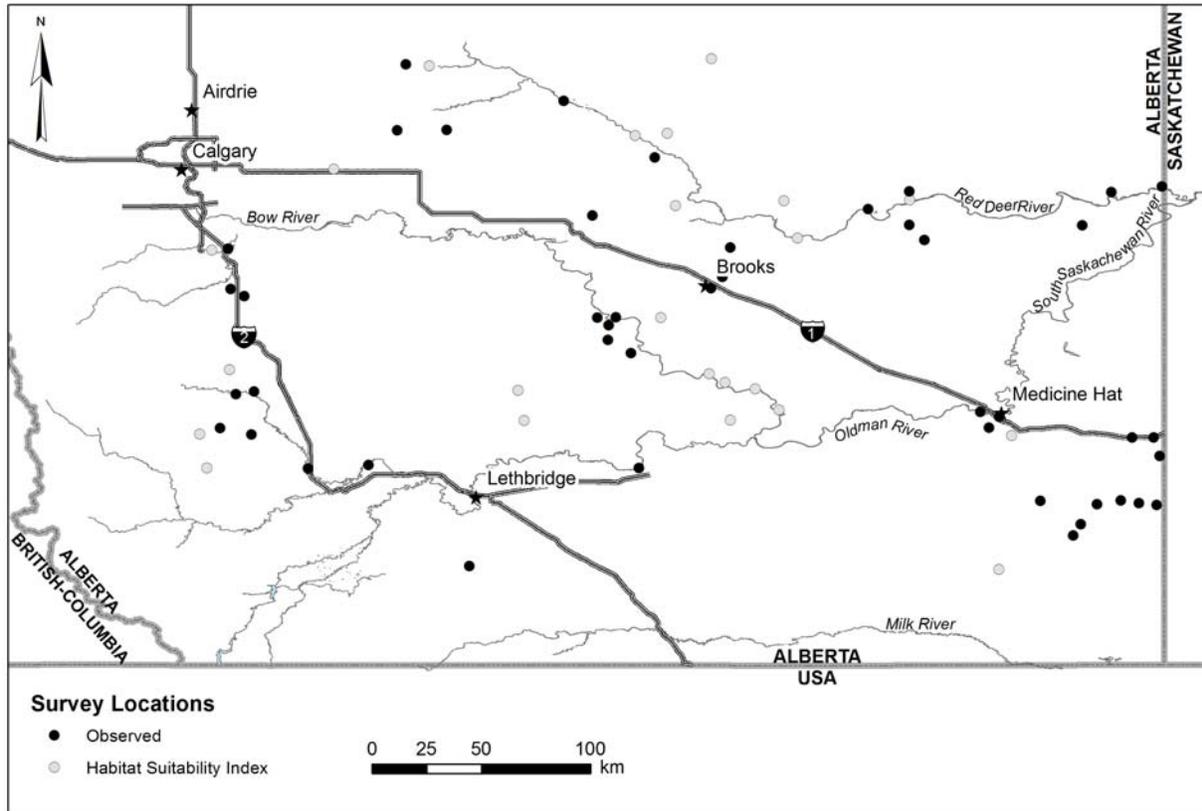


FIGURE 1. Map of study area in southeastern Alberta, Canada. Black and grey circles show the sites surveyed. Black circles are sites where Northern Leopard Frogs had previously been observed between 2005–2008 and grey circles are sites predicted by habitat modelling to have Northern Leopard Frogs (habitat suitability index).

quality Northern Leopard Frog habitat, but with no recorded surveys (Stevens et al. 2010).

At the start of field work in spring 2009, we eliminated two of the 70 selected sites; one was too difficult to access and the other was drained and cultivated. We selected one additional site that summer. We thus sampled 68 and 69 sites in spring and summer 2009, respectively. We lost access to one site, leaving 68 sites in spring and summer of 2010 and 2011. We surveyed each site four times per season, giving a total of eight repeat surveys per site per year. To maintain independence, all our sample sites were  $\geq 4$  km apart. We surveyed each site once per day over four consecutive days to minimize violations of population closure (MacKenzie et al. 2006).

**Covariate selection.**—We identified the following model covariates of  $p$ : visual obstruction, observer, wind chill, air temperature, water temperature, wind speed, humidity, dew point, time of day, Julian day, and rainfall. We measured visual obstruction (standing biomass in the riparian zone) once per season at each site using Robel transects (Robel et al. 1970). At each site during every survey, we recorded wind chill, wind speed

(average speed, km per hour, recorded over two minutes), air temperature, humidity, and dew point using Kestrel 3000 Pocket Weather Meters (Nielson-Kellerman®, Boothwyn, Pennsylvania, USA), and surface water temperature (at the start, midpoint, and end of each survey transect from which the mean was calculated) using HI98127 pH/temperature meters (Hanna Instruments®, Smithfield, Rhode Island, USA). We installed a rain gauge at each camp to record daily rainfall (see below). Observers visited different sites on different days and did not share their observations. We varied time of day systematically so that sites surveyed in the morning of one day were surveyed in the afternoon the following day.

**Survey design.**—We divided the study area into clusters of 9–14 closely-situated sites. Spring surveys were conducted soon after snow melt (between 20 April and 31 May) and summer surveys between 20 July and 31 August. We varied the order of clusters each year. During spring, we simultaneously conducted visual and aural surveys during the day involving up to one hour of slow searching and listening. Observers recorded all amphibian species seen (adults, egg masses,

metamorphs) or heard. During summer, only visual detections were possible because both species only call in spring. For large sites (e.g., lakes or canals) we searched only a portion of the site, but some small sites required less than one hour to survey. Transect length varied from 63–1,885 m and the proportion of the site surveyed varied from 0.01–1. We recorded survey time at all sites. Consecutive surveys of each site always started at the same location, with the observer moving in the same direction. This approach allowed us to standardize survey effort among years. Depending on the characteristics of the site, the observer would either walk along the edge of the waterway (e.g., at a short grass, deep water site), or wade through the water (e.g., in shallow streams or rivers with overhanging vegetation or wetland dominated by cattail (*Typha* spp.) or bulrush (*Scirpus* spp.)).

**Data analysis.**—We used the occupancy modeling approaches described in Mackenzie et al. (2006). Occupancy modeling was undertaken in Program PRESENCE 3.0 (available from <http://www.mbr-pwrc.usgs.gov/software/presence.html> [accessed 03 November 2013]). In all models, we treated detection types the same; that is, we did not discriminate between visual or aural. Prior to our analyses, all continuous covariates were standardized using *Z* scores (which express the data as the number of standard deviations an observation is above the mean) and categorical variables using dummy coding. We measured collinearity by running linear regressions between covariate pairs and then calculating variance inflation factors (VIF). Variance inflation factors quantify the severity of multicollinearity in ordinary least squares regression, providing an index of how much the variance of an estimated regression coefficient is increased by collinearity (Kutner et al. 2004). If a VIF was  $> 10$ , we considered the covariate pairing to have strong collinearity (Quinn and Keough 2002). Covariates with strong collinearity were never used in the same model, but were included in separate models, thus allowing the model selection process to decide which variable was the strongest predictor.

**Identifying covariates on *p*.**—We used separate single-season analyses (Mackenzie et al. 2006) for each of the six field seasons to determine which covariates correlated most strongly with *p*. We ranked models within each single-season analysis using AIC (Burnham and Anderson 2002) unless there was evidence of over-dispersion ( $\hat{c} > 1$ ), in which case QAIC was used (Burnham and Anderson 2002). PRESENCE 3.0 estimates the over-dispersion parameter by calculating a Pearson chi-square statistic and using bootstrapping to determine whether the value is unusually large (MacKenzie and Bailey 2004).

We developed our model sets in the following manner. A model was fitted that held *p* constant across all sites and surveys (hereafter referred to as the constant model). We used this as a reference model. We then fitted a series of models each with a single covariate of *p*. If the model in this group with the smallest AIC also had a smaller AIC value than the constant model, the covariate included in the model was used as the first covariate in a series of two covariate additive models. In the two-covariate models we paired the covariate in the top-ranked model with every other covariate (additively).

Following this step, if a two-covariate model was now the top model then we repeated the process again by working through the remaining covariates to produce a series of three covariate additive models. We did not repeat this step for four covariates. Three interaction models were run, based on combinations of variables that we thought were biologically interpretable. We ran the following interactions for spring: air temperature  $\times$  time (of day), water temperature  $\times$  Julian Day, and wind chill  $\times$  average wind speed. For summer, we ran air temperature  $\times$  time (of day), and humidity  $\times$  average wind speed.

When a model containing a covariate of *p* is run in Program PRESENCE, an estimate of *p* is made for each survey undertaken (in this case, four surveys of 68 sites resulted in 272 estimates of *p* per season). We model-averaged (Burnham and Anderson 2002) all of the survey-specific estimates of *p* across all the models in a given single-season analysis that contained  $\geq 1\%$  of the Akaike weight and were ranked above the constant model. These model-averaged estimates of *p* were then plotted against the observed covariate values for each survey to show the relationship between *p* and that covariate for that season. However, if the constant model was the top model in a given model set, we did not take these steps because it was unlikely there would be any strength to the correlations.

**Estimating spring and summer occupancy.**—To estimate occupancy we also fitted the multi-season model of MacKenzie et al. (2003) to the data, where the seasons were the three springs and three summers (i.e., six seasons). Multi-season analyses model changes in occupancy between sampling periods by estimating two additional parameters: site extinction ( $\epsilon_i$ ) and site colonization ( $\gamma_i$ ; MacKenzie et al. 2006). Occupancy probability is only estimated for the first season in a multi-season analysis with occupancy parameters for the subsequent seasons being derived using a recursive equation (MacKenzie et al. 2003).

The following models were considered for the multi-season analysis of both target species. (1) A model that held *p*,  $\gamma$ , and  $\epsilon$  constant. (2) A model that held *p* constant but allowed  $\gamma$  and  $\epsilon$  to vary with time, i.e., the interval between each season. Depending on which of

**TABLE 1.** Models of detection probability ( $p$ ) for Northern Leopard Frogs (*Lithobates pipiens*) and Boreal Chorus Frogs (*Pseudacris maculata*), 2009–2011, in Alberta, Canada. Each model is the top ranked model from a single-season analysis and occupancy is held constant in all models. (.) = constant; WC = wind chill; avgWS = average wind speed; WTemp = water temperature; JD = Julian day; Obs = observer; ATemp = air temperature; VO = visual obstruction, par = parameters. QAIC (denoted by †) was used to rank models with overdispersed data ( $c\text{-hat} > 1$ ). AIC was used to rank all other models. For each single-season analysis  $c\text{-hat}$  was estimated using the most parameterized (global) model, which is not necessarily the model presented in the table. With the exception of Northern Leopard Frogs in summer 2009 and 2011, the Akaike Weight for the constant model in each single-season analysis was  $\leq 0.001$ .

Species	Year	Season	Top Model	AIC	Akaike Weight	No. par.	Residual Deviance	C-hat
Northern Leopard Frog								
	2009	Spring	$p(\text{WC}+\text{avgWS}+\text{WC}*\text{avgWS})$	165.65	0.1787	5	155.65	~1
	2009	Summer	$p(.)$	66.67†	0.1122	2	278.89	4.45
	2010	Spring	$p(\text{WTemp}+\text{JD}+\text{avgWS})$	218.14	0.1706	5	208.22	0.38
	2010	Summer	$p(\text{JD}+\text{WC})$	90.23†	0.1143	4	190.77	2.32
	2011	Spring	$p(\text{avgWS})$	211.24	0.1905	3	205.24	~1
	2011	Summer	$p(.)$	92.01†	0.1234	2	246.04	~1
Boreal Chorus Frog								
	2009	Spring	$p(\text{WC}+\text{Obs}+\text{WTemp})$	251.27	0.1782	6	239.27	~1
	2009	Summer	$p(\text{Obs}+\text{JD})$	41.96†	0.0791	5	93.00	2.91
	2010	Spring	$p(\text{ATemp}+\text{VO})$	278.35	0.1447	4	270.35	~1
	2010	Summer	$p(\text{VO}+\text{Time}+\text{Obs})$	148.23	0.8392	6	136.23	~1
	2011	Spring	$p(\text{ATemp})$	273.74†	0.1411	3	308.14	~1
	2011	Summer	$p(\text{VO}+\text{avgWS}+\text{JD})$	196.08	0.2131	5	186.08	~1

these two models had the smallest AIC, the next four models held either  $\gamma$  and  $\epsilon$  constant or allowed them to vary with time. (3) a model where the design matrix for  $p$  was constrained to represent the results of the six single-season analyses (e.g., if wind chill was important for Northern Leopard Frogs in spring 2009 and rainfall in summer 2009 then the design matrix would reflect this); the design matrix was also constrained to allow each of the six sampling occasions to have a different intercept. We standardized covariates in the manner described for single-season analyses.

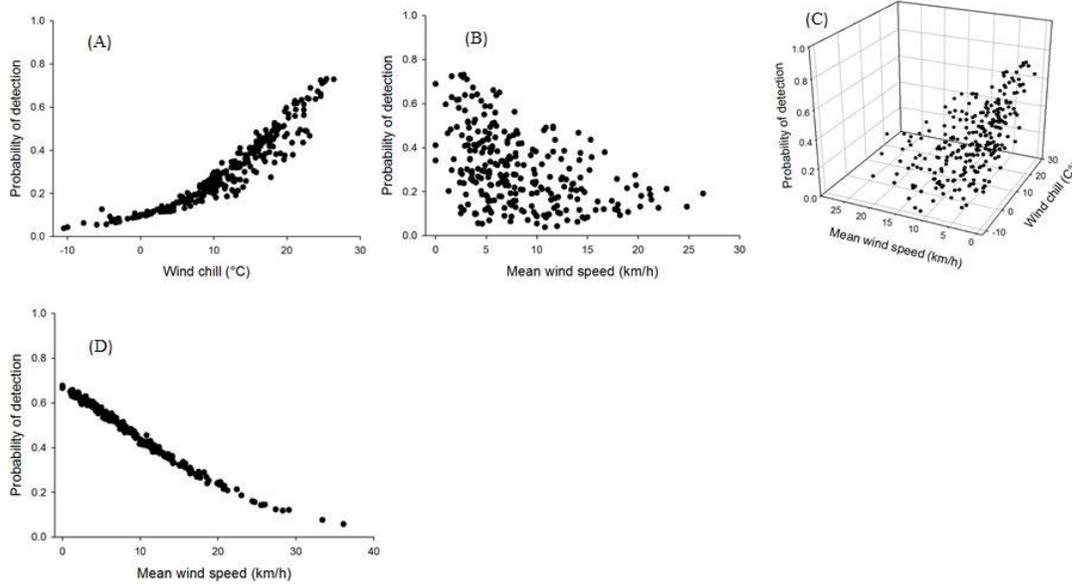
We used these models to make seasonal comparisons of occupancy and to contrast model estimates with naïve estimates of occupancy. Naïve estimates were calculated as a percentage of sites where we detected species during the first survey, mirroring the current standard of single surveys. We also used histograms to assess the type of detection most common for each species and whether it differed among seasons.

**RESULTS**

**Impact of covariates on probability of detection.**— There was little collinearity between covariates with the exception of wind chill and air temperature (adjusted  $r^2 = 0.97$ ) which shared a VIF of 28.28. Consequently, wind chill and air temperature were not included together in the same models. Probability of detection of

Northern Leopard Frogs was most strongly predicted by temperature-related variables or by wind speed (Table 1; Fig. 2). The predictive ability of these covariates was typically stronger in spring compared with summer (see Table 1; constant model was the top model in two out of three summers). Temperature-related covariates predicted detectability of Boreal Chorus Frogs, but visual obstruction and observer were also important predictors (Table 1; Fig. 3), with visual obstruction having a strong negative relationship with  $p$  during summer 2010 and 2011. Wind speed was only included in the top Boreal Chorus Frog model once (summer 2011) compared with three times for Northern Leopard Frogs. The constant model was never the top model for Boreal Chorus Frogs (although it was second to the top model for summer 2009).

The strength of relationships between covariates and  $p$  showed strong variation among years and seasons. For instance, in spring 2009 wind chill was strongly positively correlated with  $p$  for Northern Leopard Frogs, whereas mean wind-speed was weakly negatively correlated (Fig. 2). An interaction effect between these two variables indicated that even at low wind-speeds, cold wind reduced  $p$ . In contrast, in spring 2011 mean wind speed tightly correlated with  $p$  for Northern Leopard Frogs. For Boreal Chorus Frogs, wind chill and water temperature were important correlates of  $p$  in

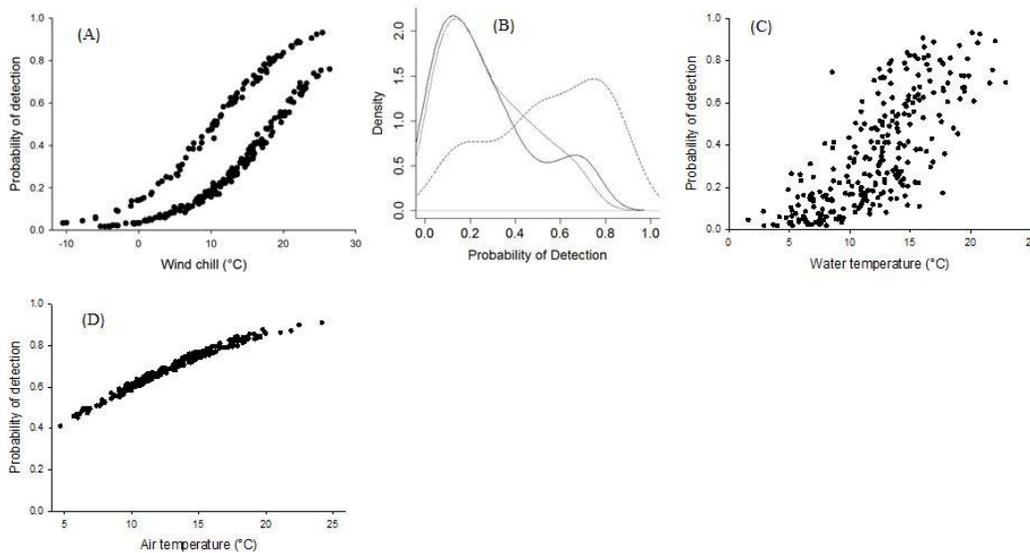


**FIGURE 2.** Detection probability ( $p$ ) and covariates for Northern Leopard Frogs. Graphs are model averaged estimates of  $p$  (across all models that had AIC weight  $\geq 1\%$ ) from each single-season analysis against the raw covariate values (only for covariates included in the top model). (A), (B), (C) = spring 2009; (D) = spring 2011. During spring 2009,  $p$  was strongly correlated with wind chill, but this interacted with wind speed. In spring 2011,  $p$  was strongly correlated with wind speed alone.

spring 2009, whereas in spring 2010 and 2011  $p$  positively correlated with air temperature (Fig. 3).

**Spring and summer occupancy.**—The top multi-season model for Northern Leopard Frogs included the design matrix constrained to represent the top models from the six single-season analyses. It had a separate intercept for

each field season (Table 2). Estimates from this model showed that Northern Leopard Frog occupancy was lower in spring than summer 2009 and was relatively constant across all summers (Table 3). This was also the top model for Boreal Chorus Frogs (Table 4). Boreal Chorus Frog occupancy seemed more variable than Northern Leopard Frog occupancy, and dipped strongly



**FIGURE 3.** Two examples of how covariates influence  $p$  (spring 2009 and spring 2011) for Boreal Chorus Frogs. Graphs are the model averaged estimates of  $p$  (modeled across all models that had an AIC weight of  $\geq 1\%$ ) from each single-season analysis against the raw covariate values (only for covariates included in the top model). (A), (B), (C) = spring 2009; (D) = spring 2011. In spring 2009  $p$  was strongly correlated with wind chill, but observer and water temperature were also important. Density plots for three different observers (B), indicating that one observer had a much higher chance of observing Boreal Chorus Frogs than the other two observers. In spring 2011 the strongest correlation was between  $p$  and air temperature.

**TABLE 2.** Multi-season analysis of Northern Leopard Frogs (*Lithobates pipiens*). (.) = constant; (t) = varying with time; cov = where the design matrix represents the top models from the six single season analyses; varying intercepts = six intercepts, one for each field season.

Model	AIC	Δ AIC	Akaike Weight	No. par.	Residual Deviance
$\psi, \gamma(t), \varepsilon(t), p(\text{Cov})$ varying intercepts	1283.5	0	1	34	1215.55
$\psi, \gamma(t), \varepsilon(t), p(.)$	1465.0	181.5	0	12	1440.95
$\psi, \gamma(.), \varepsilon(.), p(.)$	1519.4	235.8	0	4	1511.35

in summer 2009 compared with spring (Table 3). The drop was smaller in summer 2011.

Compared to the model-based estimates of occupancy, naïve estimates were strongly negatively-biased (Table 3). Naïve estimates of occupancy were only within the 95% confidence limits of associated model-based

estimates for Northern Leopard Frogs in summer 2010, and for Boreal Chorus Frogs in spring 2009, summer 2009, and summer 2010. For Northern Leopard Frogs,  $p$  was higher in summer than spring during all three years (Table 5). Boreal Chorus Frogs showed the opposite pattern, with  $p$  consistently higher in spring than summer (Table 5). Spring detections of Northern Leopard Frogs were mainly by visual observation (60% of detections) whereas Boreal Chorus Frogs were mainly detected aurally (80% of detections; Fig. 4). During summer, the only method of detection for both species was visual observation (Fig. 4).

**DISCUSSION**

Our results show that single surveys of Northern Leopard Frogs and Boreal Chorus Frogs on Canada’s prairies are negatively biased and therefore may not always detect the species when they are present. Currently in Alberta, the minimum number of wetland surveys necessary to determine the presence or absence of a threatened or endangered amphibian species is not specified (ASRD 2010). Consequently, most

environmental consultants only do single surveys in locations that may conflict with resource extraction or development. Our results suggest that single surveys for anurans on the northern prairies are indefensible, and this likely holds true for other regions of the world.

Estimating and accounting for imperfect detection when surveying anurans will lead to less-biased estimates of occupancy (Mazerolle et al. 2007). However, precision of parameter estimates can be improved further if periods of low  $p$  are avoided (Williams et al. 2002). Many of the covariates we measured correlated strongly with  $p$ , but the strength of correlations varied between seasons and years. For instance, in spring 2009, wind chill and wind speed together predicted  $p$ , but in spring 2010 wind speed alone was the strongest predictor. In most seasons, temperature and wind strongly influenced the probability of detecting Northern Leopard Frogs, suggesting that surveys should not be undertaken on days of moderate-to-strong wind strength, and cold wind should be avoided even at low velocities. For instance, in spring 2009,  $p$  was  $\leq 0.2$  when wind chill was below 10° C and  $p$  fell below 0.5 when wind speed was  $> 10$  km per hour. Probability of detection improved during spring 2010 surveys when water temperatures were  $\geq 15$  °C, suggesting that low water temperature surveys will coincide with low  $p$ . The probability of detecting Northern Leopard Frogs was considerably higher in summer, and was likely improved by the high abundance

**TABLE 3.** Estimates of proportion of area occupied for Northern Leopard Frogs (*Lithobates pipiens*) and Boreal Chorus Frogs (*Pseudacris maculata*), 2009–2011, in Alberta, Canada. Modeled estimates ( $\pm$  95% CI) are from multi-season occupancy analyses. Single survey (i.e., naïve estimates) are based on the first survey of each site in each season.

	Spring			Summer		
	2009	2010	2011	2009	2010	2011
<u>Northern Leopard Frog</u>						
Occupancy modeling	0.41 (0.25–0.61)	0.57 (0.45–0.69)	0.53 (0.38–0.68)	0.55 (0.43–0.69)	0.55 (0.41–0.69)	0.56 (0.44–0.68)
Single survey	0.12	0.24	0.13	0.41	0.46	0.38
<u>Boreal Chorus Frog</u>						
Occupancy modeling	0.70 (0.56–0.84)	0.36 (0.13–0.59)	0.68 (0.55–0.81)	0.61 (0.35–0.88)	0.74 (0.63–0.84)	0.50 (0.33–0.67)
Single survey	0.29	0.38	0.41	0.4	0.7	0.18

**TABLE 4.** Multi-season analysis of Boreal Chorus Frogs (*Pseudacris maculata*). Symbols (.) = constant; (t) = varying with time; cov = where the design matrix represents the top models from the six single season analyses; varying intercepts = six intercepts, one for each field season; par. = parameters.

Model	AIC	Δ AIC	Akaike Weight	No. parameters	Residual Deviance
$\psi, \gamma(t), \varepsilon(t), p(\text{Cov})$ varying intercepts	1267.66	0	1	26	1215.66
$\psi, \gamma(t), \varepsilon(t), p(.)$	1398.91	131.25	0	12	1374.91
$\psi, \gamma(.), \varepsilon(.), p(.)$	1417.55	149.89	0	4	1409.55

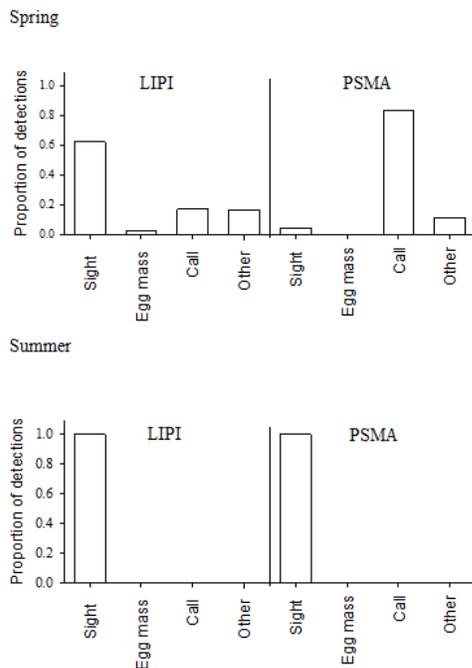
of metamorphs.

In several seasons, observer and visual obstruction influenced the probability of detecting Boreal Chorus Frogs. Observer was a covariate in the top-ranked models for both spring and summer. This suggests that the attention of observers differs when listening for calls, and in spotting this small frog amongst vegetation in late-summer when they are scarce. Enhanced training or screening of observers could improve accuracy. The negative relationship with visual obstruction in late summer suggests that visual walking surveys are unreliable for Boreal Chorus Frogs during that part of the season. This is particularly important in locations where vegetation density exceeds a Robel index of 20–30. There are more effective ways to conduct localized

intensive surveys for Boreal Chorus Frogs. Examples include dip netting for larvae in the spring and intensive hands and knee searches of the grass adjacent to waterways in the summer. Temperature variables were also important predictors of  $p$  for Boreal Chorus Frogs, particularly in spring, suggesting they have higher calling rates on warmer days (air temperature  $\geq 15^\circ\text{C}$  will likely result in  $p \geq 0.5$ ). Interestingly, our springtime estimates of  $p$  for Boreal Chorus Frogs were much lower (0.36–0.7; Table 5) than the 0.83–0.96 estimated by Gould et al. (2012) from the Yellowstone and Grand Teton National Park area. This difference is possibly because of colder temperatures in our more northern study area.

Local authorities and consultants surveying frogs in prairie Canada typically use daytime surveys. We used daytime walking transects to survey both species visually and aurally. Contrasting seasonal detection probabilities suggest that different seasons or methods should be used for each target species when using daytime walking transects. Northern Leopard Frogs should be surveyed in late summer when most detections are sightings of young-of-the-year or adults, whereas Boreal Chorus Frogs should be surveyed in spring when most detections will be from calls.

The equation  $(1 - p)^n$  quantifies the probability of not detecting the species, where  $p$  is detection probability and  $n$  is the number of surveys (e.g., Tyre et al. 2003). Based on our study, a survey for Northern Leopard Frogs over two consecutive days in late-summer should yield an overall  $p \geq 0.9$ , i.e.,  $1 - (1 - 0.7)^2 = 0.9$ . This is a high confidence of detecting the species when it is



**FIGURE 4.** Proportion of detections of Northern Leopard Frogs (LIPI) and Boreal Chorus Frogs (PSMA) during walking surveys. Data are for spring and summer 2009–2011. Sight = frog species identified by sighting one or more egg masses; call = species identified by hearing their call; other = detection occurred by more than one method (e.g., sighting an individual frog and an egg mass during the same survey).

**TABLE 5.** Probability of detection for Northern Leopard Frogs (*Lithobates pipiens*) and Boreal Chorus Frogs (*Pseudacris maculata*), 2009–2011, in Alberta, Canada. Values are the mean of model-averaged estimates.

	Spring			Summer		
	2009	2010	2011	2009	2010	2011
Northern Leopard Frog	0.30	0.31	0.44	0.71	0.77	0.79
Boreal Chorus Frog	0.36	0.54	0.68	0.25	0.18	0.45

present, and should contribute to high-precision estimates for Northern Leopard Frog occupancy. The probability of detecting Boreal Chorus Frogs in spring using daytime searches was much more variable, and would have taken  $\geq 4$  days of consecutive surveys to achieve a similar overall level of confidence. In an analysis of 252 animal species monitored at 85 sites, Nielsen et al. (2009) demonstrated that at least 50 sites with 66% detectability and 50% occupancy need to be surveyed to detect a 3% annual change in species occupancy. Conducting two consecutive daytime surveys of Northern Leopard Frogs in late summer in prairie Canada meets this requirement.

The boreal/prairie Northern Leopard Frog population in Canada is considered at risk, having declined since the 1980s and disappeared from parts of the region (COSEWIC 2009). We estimated that Northern Leopard Frogs occupied approximately 57% of the sampled sites. In contrast to Northern Leopard Frogs, Boreal Chorus Frogs are considered of low priority for conservation (Committee on the Status of Endangered Wildlife in Canada. 2012. *op. cit.*). Our spring surveys suggested that Chorus Frog occupancy was relatively consistent over the 3 years, but summer surveys provided highly-variable occupancy estimates. Summer variability might have been caused by Boreal Chorus Frogs moving away from breeding sites (Cynthia Paszkowski, pers. comm.).

**Conclusions.**—Our study showed that occupancy data collection for Northern Leopard Frogs and Boreal Chorus Frogs would best be undertaken using a different survey approach for each species. If there is specific interest in a particular species (e.g., because they are the target for conservation management), significant improvements in monitoring can be made by understanding what period of the year  $p$  is highest for that species. Additional gains might be made by understanding what environmental variables correlate with  $p$ , but these could be highly variable between years and the time of year.

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### LITERATURE CITED

- ASRD (Alberta Sustainable Resource Development). 2010. Sensitive species inventory guidelines. Government of Alberta, Red Deer, Alberta, Canada. 74 p.
- Biek, R., W.C. Funk, B.A. Maxwell, and L.S. Mills. 2002. What is missing in amphibian decline research: insights from ecological sensitivity analysis. *Conservation Biology* 16:728–734.
- Bridges, A.S., and M.E. Dorcas. 2000. Temporal variation in anuran calling behaviour: implications for surveys and monitoring programs. *Copeia* 2000:587–592.
- Browne, C.L., C.A. Paszkowski, A.L. Foote, A. Moenting, and S.M. Boss. 2009. The relationship of amphibian abundance to habitat features across spatial scales in the Boreal Plains. *Ecoscience* 16:209–223.
- Burnham, K.P., and D.R. Anderson. 2002. *Model Selection and Multimodel Inference: a Practical Information-theoretic Approach*. 2<sup>nd</sup> Edition. Springer Science + Business Media, LLC, New York, New York, USA.
- Corn, P.S., and L.J. Livo. 1989. Leopard Frog and Wood Frog reproduction in Colorado and Wyoming. *Northwestern Naturalist* 70:1–9.
- COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2009. COSEWIC assessment and update status report on the Northern Leopard Frog *Lithobates pipiens*, Rocky Mountain population, Western Boreal/Prairie populations in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, Ontario, Canada. 69 p.
- Cunjak, R.A. 1986. Winter habitat of Northern Leopard Frogs, *Rana pipiens*, in a southern Ontario stream. *Canadian Journal of Zoology* 64:255–257.
- de Solla, S.R., L.J. Shirose, K.J. Fernie, G.C. Barrett, C.S. Brousseau, and C.A. Bishop. 2005. Effect of sampling and species detectability on volunteer based anuran monitoring programs. *Biological Conservation* 121:585–594.
- Emery, A.R., A.H. Berst, and K. Kodaira. 1972. Under-ice observations of wintering sites of leopard frogs. *Copeia* 1972:123–126.
- Gilbert, M., R. Leclair, Jr., and R. Fortin. 1994. Reproduction of the Northern Leopard Frog (*Rana pipiens*) in floodplain habitat in the Richelieu River, Quebec, Canada. *Journal of Herpetology* 28:465–470.
- Gould, W.R., D.A. Patla, R. Daley, P.S. Corn, B.R. Hossack, R. Bennetts, and C.R. Peterson. 2012. Estimating occupancy in large landscapes: evaluation

- of amphibian monitoring in the Greater Yellowstone Ecosystem. *Wetlands* 32:379–389.
- Kendall, K. 2002. Alberta inventory for the Northern Leopard Frog (2000/2001). Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 44, Edmonton, Alberta, Canada. 29 p.
- Kendall, K., S. Stevens, and D.R.C. Prescott. 2007. Alberta Northern Leopard Frog survey, 2005. Technical Report, T-2007-001, Alberta Conservation Association, Edmonton, Alberta, Canada. 17 p. + App.
- Kutner, M.H., C.J. Nachtsheim, and J. Neter. 2004. *Applied Linear Regression Models*. 4<sup>th</sup> Edition. McGraw-Hill, Columbus, Ohio, USA.
- Lotz, A., and C.R. Allen. 2007. Observer bias in anuran call surveys. *Journal of Wildlife Management* 71:675–679.
- MacKenzie, D.I., and L.L. Bailey. 2004. Assessing the fit of site-occupancy models. *Journal of Agricultural, Biological, and Environmental Statistics* 9:300–318.
- MacKenzie, D.I., J.D. Nichols, J.E. Hines, M.G. Knutson, and A.B. Franklin. 2003. Estimating site occupancy, colonization and local extinction when a species is detected imperfectly. *Ecology* 84:2200–2207.
- MacKenzie, D.I., J.D. Nichols, G.B. Lachman, S. Droege, J.A. Royle, and C.A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83:2248–2255.
- MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2006. *Occupancy Estimation and Modelling: Inferring Patterns and Dynamics of Species Occurrence*. Academic Press, San Diego, California, USA.
- Marsh, D.M., and P.C. Trenham. 2001. Metapopulation dynamics and amphibian conservation. *Conservation Biology* 15:40–49.
- Mazerolle, M.J., L.L. Bailey, W.L. Kendall, J.A. Royle, S.J. Converse, and J.D. Nichols. 2007. Making great leaps forward: accounting for detectability in herpetological field studies. *Journal of Herpetology* 41:672–689.
- McCallum, M.L. 2007. Amphibian decline or extinction? Current declines dwarf background extinction rate. *Journal of Herpetology* 41:483–491.
- Merrell, D.J. 1977. Life History of the Leopard Frog, *Rana pipiens*, in Minnesota. Bell Museum of Natural History, Minneapolis, Minnesota, USA.
- Nielsen, S.E., D.L. Haughland, E. Bayne, and J. Schieck. 2009. Capacity of large-scale, long-term biodiversity monitoring programmes to detect trends in species prevalence. *Biodiversity and Conservation* 18: 2961–2978.
- Paszowski, C.A., G. Scrimgeour, B.A. Gingras, and S. Kendall. 2002. A comparison of techniques for assessing amphibian assemblages on streams in the Western Boreal Forest. *Canadian Field Naturalist* 116:116–119.
- Quinlan, R.W., B.A. Downey, B.N. Taylor, B.F. Jones, and T.B. Clayton. 2003. A multi-species conservation strategy for species at risk in the Milk River basin: year 1 progress report. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 72, Edmonton, Alberta, Canada. 229 p.
- Quinn, G.P., and M.J. Keough. 2002. *Experimental Design and Data Analysis for Biologists*. Cambridge University Press, Cambridge, UK.
- Robel, R.J., J.N. Briggs, A.D. Dayton, and L.C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. *Journal of Range Management* 23:295–297.
- Russell, A.P., and A.M. Bauer. 2000. *The Amphibians and Reptiles of Alberta: A Field Guide and Primer of Boreal Herpetology*. University of Calgary Press, Calgary, Alberta, Canada.
- Schlichter, L.C. 1981. Low pH affects the fertilization and development of *Rana pipiens* eggs. *Canadian Journal of Zoology* 59:1693–1699.
- Sewell, D., T.J.C. Beebee, and R.A. Griffiths. 2010. Optimising biodiversity assessments by volunteers: the application of occupancy modeling to large-scale amphibian surveys. *Biological Conservation* 143:2102–2110.
- Shorthouse, J.D. 2010. Ecoregions of Canada's prairie grasslands. Pp. 53–81 *In* *Arthropods of Canadian Grasslands: Ecology and Interactions in Grassland Habitats*. Shorthouse, J.D., and K.D. Floate (Eds.). Biological Survey of Canada, Ottawa, Ontario, Canada.
- Smith, M.A., and D.M. Green. 2005. Dispersal and the metapopulation paradigm in amphibian ecology and conservation: are all amphibian populations metapopulations? *Ecography* 28:110–128.
- Sparling, D.W. 2010. Water-quality criteria for amphibians. Pp. 105–120 *In* *Amphibian Ecology and Conservation: A Handbook of Techniques*. Dodd, C.K. (Ed.). Oxford Biology, New York, New York, USA.
- Stevens, S.D., D.R.C. Prescott, and D. Page. 2010. Habitat suitability index for the Northern Leopard Frog in Alberta: model derivation and validation. Alberta Sustainable Resource Development, Fish and Wildlife Department, Edmonton, Alberta, Canada. 16 p.
- Tyre, A.J., B. Tenhumberg, S.A. Field, D. Niejalke, K. Parris, and H.P. Possingham. 2003. Improving precision and reducing bias in biological surveys: estimating false-negative error rates. *Ecological Applications* 13:1790–1801.
- Vonesh, J.R., J.C. Mitchell, K. Howell, and A.J. Crawford. 2010. Rapid assessments of amphibian

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biodiversity. Pp. 263 *In Amphibian Ecology and Conservation: a Handbook of Techniques*. Dodd, C.K. (Ed.). Oxford Biology, New York, New York, USA.

Weir, L., I.J. Fisk, and J.A. Royle. 2009. Trends in anuran occupancy from northeastern states of the North American Amphibian Monitoring Program. *Herpetological Conservation and Biology* 4:389–402.

Weir, L.A., J.A. Royle, P. Nanjappa, and R.E. Jung. 2005. Modeling anuran detection and site occupancy on North American Amphibian Monitoring Program (NAAMP) routes in Maryland. *Journal of Herpetology* 39:627–639.

Williams, B.K., J.D. Nichols, and M.J. Conroy. 2002. *Analysis and Management of Animal Populations*. Academic Press, San Diego, California, USA.

**APPENDIX 1.** Sampling effort required to achieve a given level of precision (SE) for  $\psi$  and  $p$  assuming constant probability of detection across sites. Sites = number of sites needed to be visited; surveys = number of times each site would need to be surveyed;  $\psi$  = the probability that the site is occupied;  $p$  = the probability of detecting the species at a site if that site is occupied.  $\Psi$  of 0.4 and 0.2 are based on the 2001 and 2005 census surveys for Northern Leopard Frogs (Kendell 2002; Kendell et al. 2007). The values for  $p$  of 0.8, 0.7, and 0.5 are a cross section of possibilities assuming that  $p$  is higher in late summer, while the values of 0.5, 0.4, and 0.2 are a cross section of possibilities assuming that  $p$  is lower in spring.

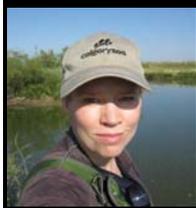
$\psi$	$p$	SE 0.05		SE 0.07		SE 0.1		SE 0.15	
		Sites	Surveys	Sites	Surveys	Sites	Surveys	Sites	Surveys
<i>Summer</i>									
<i>Assuming approximately 40% of sites are occupied</i>									
0.4	0.8	106	2	54	2	27	2	11	2
0.4	0.7	125	2	64	2	31	2	14	2
0.4	0.5	136	3	70	3	34	3	15	3
<i>Assuming approximately 20% of sites are occupied</i>									
0.2	0.8	69	2	35	2	17	2	8	2
0.2	0.7	79	2	40	2	20	2	9	2
0.2	0.5	84	3	43	3	21	3	9	3
<i>Spring</i>									
<i>Assuming approximately 40% of sites are occupied</i>									
0.4	0.5	136	3	70	3	34	3	15	3
0.4	0.4	136	4	70	4	34	4	15	4
0.4	0.2	152	8	78	8	38	8	17	8
<i>Assuming approximately 20% of sites are occupied</i>									
0.2	0.5	84	3	43	3	21	3	9	3
0.2	0.4	84	4	43	4	21	4	9	4
0.2	0.2	104	7	53	7	26	7	12	7



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