Determination of optimal sampling designs for occupancy modeling of amphibian species in the Columbia Basin

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Executive summary

This report provides an outline for the use of occupancy models for inference on occupancy and estimation of trends in occupancy for amphibians as part of the Columbia Basin Amphibian Inventory Program. To estimate occupancy requires repeated visits to the same amphibian site so that detection probability and occupancy can be estimated. At this point, no sites in the inventory area have been visited more than once and therefore the only data is available on naïve uncorrected occupancy. Therefore, the main objective of this paper is to consider optimal designs needed to obtain data for estimation of detection rate and true occupancy. With this data, it will be possible to design a precise optimized long-term sampling design for the amphibians. I used simulation methods and closed formulas to approximate the number of sites and sessions needed to obtain single year estimates of occupancy and detection rates for 4 focal amphibian species and all species combined with an emphasis on the Western Toad which is a species of immediate conservation concern. For all designs I considered field sampling consisting of 2 independent observers so that 2 independent sampling sessions could be conducted in a single visit to a site. In general, a design with 80 sites sampled for 4 sessions (2 visits) or a design with 80 sites in which a proportion were sampled for 4 sessions was needed to obtain estimates of western toad occupancy with adequate precision given a naïve occupancy estimate of western toads of 0.28. This design was adequate for all other species except the Pacific Chorus Frog that displayed low occupancy in the northern districts. Other factors, such as sample size required to model temporal variation, collection of covariates, scale of inference, sample site selection, trend estimation models, and estimation of breeding site encounter rates are also discussed.

Acknowledgements

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Introduction

This report provides an outline for the use of occupancy models for inference on distribution and trend estimation of amphibians for the Columbia Basin Amphibian Inventory Program. Much of the Columbia Basin has been previously sampled using the U.S. Geological Survey's Amphibian Research and Monitoring Initiative (ARMI; www.armi.usgs.gov) (Dulisse and Hausleitner 2009;2010;2011). The objective of this report is to use the data from these baseline reconnaissance surveys to design studies that estimate occupancy and eventual trends in occupancy. The objectives of the monitoring program are outlined below.

1. To detect changes in the number of sites occupied and the breeding site encounter rate between sampling sessions on two scale levels including:
    a. Coarse scale - total number of amphibian species grouped together
    b. Fine scale -by individual species.
2. To estimate the change in occupancy and determine if it is significant.
3. If there is a change in occupancy detected, to determine if the scale in which the change occurs is on a regional or site level scale.
4. To determine the potential cause of change based on site-level, temporal, and region level covariate data.

When wetland sites are visited it is possible that some amphibian species may be present but not detected. To confront this issue, occupancy models were developed to estimate the probability of detecting an amphibian species when a wetland is visited, and from this estimate true occupancy for a series of wetlands that are sampled (MacKenzie et al. 2002). These models have been applied successfully to amphibian species throughout the United States and Canada (www.armi.usgs.gov). Occupancy models use the sequences of detections and non-detections at sites to estimate the probability of detecting a species, and from that the actual number of sites that were occupied using a mark-recapture methodology that is very similar to estimation of population size (MacKenzie et al. 2002, Boulanger et al. 2008). From this, the true proportion of occupied sites is also estimated.

Occupancy estimation involves repeated visits to a "site" so that the probability of detection of an amphibian species and the occupancy probability can be estimated. Factors such as the cryptic nature of amphibian species, timing of vocalizations, weather, site characteristics, and timing of field surveys may influence the probability of detection. With repeat visits to each site, a series of detection and non-detections is obtained accompanied by the understanding that at some sites the species might have been present but not detected. This type of data collection then allows the estimation of occupancy probability to account for "missed" detections.

In the methods used in past surveys for the Columbia Basin Amphibian Inventory, no sites were visited more than once and therefore only data is available on "naïve" uncorrected occupancy (the product of detection probability (p) and true occupancy probability (Ψ)). Therefore, the main objective of this paper is to consider optimal designs needed to obtain data for estimation of detection rate and true occupancy in order to develop a precise optimized long-term sampling design for the amphibians. Fundamental to this approach is the avoidance of "pilot data" that may not be valuable for longer term monitoring efforts. Instead, I focus on an optimized single season design that will be used as the first year of occupancy monitoring data and will allow the adaptive adjustment of study design and sampling effort in future years.

Methods

Determining likely values of occupancy and detection rate

At this time, only naïve occupancy estimates are available for amphibians in the survey area since all surveys have only conducted a single session of sampling (Table 1). In this case, naïve occupancy is the product of detection probabilities (*p*) times the true occupancy probability (Ψ). Given that detection rates seldom equal 1,it is likely that true occupancy will be higher than naïve occupancy values

Table 1: A summary of detections of focal amphibian species in the Arrow-Boundary &Kootenay Lake, Columbia, and Headwaters Forest Districts from Dulisse and Hausleitner (2009;2010;2011)

Region	Species					
	Sites	At least one species	Columbia Spotted Frog	Pacific Chorus Frog	Long-Toed Salamander	Western Toad
Kootenay Boundary						
Detections	40	36	29	17	16	11
Naïve occupancy		0.90	0.73	0.43	0.40	0.28
Columbia						
Detections	43	38	32	2	12	12
Naïve occupancy		0.88	0.74	0.05	0.28	0.28
Headwaters						
Detections	43	31	24	2	6	12
Naïve occupancy		0.72	0.56	0.05	0.09	0.28
All areas						
Total detections	126	105	86	21	34	35
Mean naive occupancy		0.83	0.68	0.17	0.27	0.28

Estimates of detection probability were required to assess optimal occupancy sampling designs. I therefore performed a literature search and found published detection (and occupancy rates) for studies that used similar methods. Often detection probability estimates were based on values of various factors such as whether amphibians were breeding or fish were present. In that case, I display a range of values and suggest that the lower values of detection rate should be considered when interpreting potential study designs (Table 2).

Table 2: A summary of occupancy and detection probabilities from literature sources for focal amphibian species

Species	Occupancy	detection	sessions	sites	study location (source)
Columbia Spotted Frog	65.6	57.4	2-4	23	BC (Hausleitner and Dulisse 2011)
Western Toad	84.9	0.67-0.84	1-2	54	Oregon (Pearl et al. 2009)
Columbia Spotted Frog	0.31-0.38	0.46-0.69	2	83	Montana (Hossack and Corn 2007)
Long-Toed Salamander	0.86-0.89	0.85-0.89	2	83	Montana (Hossack and Corn 2007)

Assessing optimal sampling designs for initial occupancy sampling

There are a variety of potential sampling designs that are available for occupancy estimation in future work, as summarized in Table 3.

Table 3: Summary of potential designs for occupancy estimation.

Design	Description	Rationale for use/non use
Standard design	All sites are visited each year for the same number of sessions	Most flexibility for modeling detection and occupancy rate variation but less sites can be visited (MacKenzie and Royle 2005)
Removal design	A site is only visited until a species is detected	Allows more sites to be visited but limits the ability to model detection rate variation (MacKenzie and Royle 2005)
Double sampling design	A subset of sites is visited twice and the rest are visited once	Allows more sites to be visited but overall less efficient estimates(MacKenzie and Royle 2005)
Rotating panel	Sites are visited repeatedly intermittently in a multi-year program	Allows more sites to be visited but can cause confounding of spatial and temporal variation (Bailey et al. 2007)

Given that no occupancy data has been collected for the study area, I suggest that the standard design be used initially for the majority of sites to allow full investigation of likely covariates for detection probabilities and occupancy probabilities. After the initial data collection year, it will be possible to make more informed decisions on the feasibility of other designs that make more restrictive assumptions. However, given that it may not be practical to sample all sites for the same number of sessions as recommended in the Standard design an alternative would be a panel-type design (as discussed below)where a subset of sites is visited for more than a single visit (with two observers) which would allow valuable inference on temporal variation in detection rates while increasing the sample size of sites.

In order to obtain estimates of occupancy, a site needs to be sampled for at least two sessions. One of the main costs of sampling is the transportation of field personnel to the sample sites. One design that provides two sessions within a single visit is if two field personnel visit the site and collect independent observations on occupancy. For this approach, observers collect similar length transects of the wetland and do not communicate about any detections of amphibians. The transects are standardized and alternated between observers to ensure that sampling is random and independent between observers. This general sampling strategy was used to estimate the occupancy and detection of Columbia Spotted Frogs on Ventigo Creek (Hausleitner and Dulisse 2011). Given the practicality of this design, it is the best field sampling strategy for occupancy sampling.

Evaluation optimal sampling design

I used the range of occupancy and detection rates to assess the approximate number of sites and sessions that would be needed to obtain occupancy estimates with a coefficient of variation of less that 20%. Coefficient of variation (CV) is the standard error of an estimate divided by the estimate expressed as a percentage. A CV of 20% is considered the upper limit on mark-recapture type estimates for management and trend monitoring (Pollock et al. 1990). I used the sample size formulas of MacKenzie and Royle (2005) to estimate levels of precision and the number of sites and sessions needed to obtain occupancy estimates with adequate precision. In order to investigate more exact designs, I used simulation modules that are included in program GENPRES (Bailey et al. 2007).

If a data set with occupancy estimate CV levels of 20% or less is obtained, then it should be possible to further refine the longer-term sampling strategy using actual estimates of occupancy and detection rates. Most power analyses of mark-recapture modeling have suggested that it is possible to reduce sampling after initial sampling efforts are completed with minimal loss of power to detect longer-term trends (Pollock et al. 1990, Boulanger 2005). So the general rationale behind the initial year of sampling is to collect a rich data set that would explain existing spatial and temporal variation (within a single season), therefore, allowing a precise adjustment of sampling effort in future years of monitoring.

Results and Discussion

Sample designs needed to obtain precise occupancy estimates

As an initial step, I considered the ranges of occupancy from Table 1 and the estimates of detection rate from the literature (Table 2). Following these steps, I used the formulas of McKenzie and Royle (2005) to estimate the number of sessions and sites needed to obtain a single-season occupancy estimate with a coefficient of variation of less than 20% (Figures 1 and 2). It can be seen that the number of sites needed depends greatly on the occupancy rates; species that have lower occupancy require more sites than species with higher occupancy.

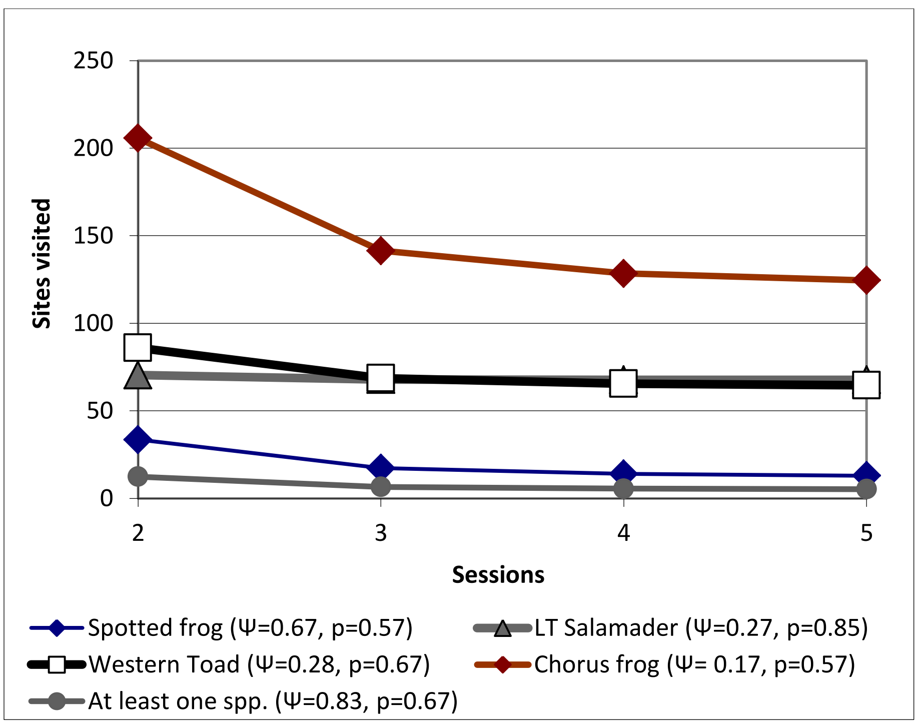

Figure 1: The number of sites and sampling sessions needed to obtain a point estimate of occupancy with a coefficient of variation of less that 20%. Occupancy rates (Ψ) are from Table 1 with values of detection probability (p) taken from other studies (Table 2).

The Long-Toed Salamander and the Pacific Chorus Frog were primarily found in the Kootenay Boundary Forest district so it could be argued that occupancy should mainly be considered for this area in regards to these species. To explore this, I then used occupancy estimates for this area and these species. It can be seen that the number of sites required was further reduced for these species. However, the Western Toad still required between 65 and 90 sites dependent on the number of sessions sampled.

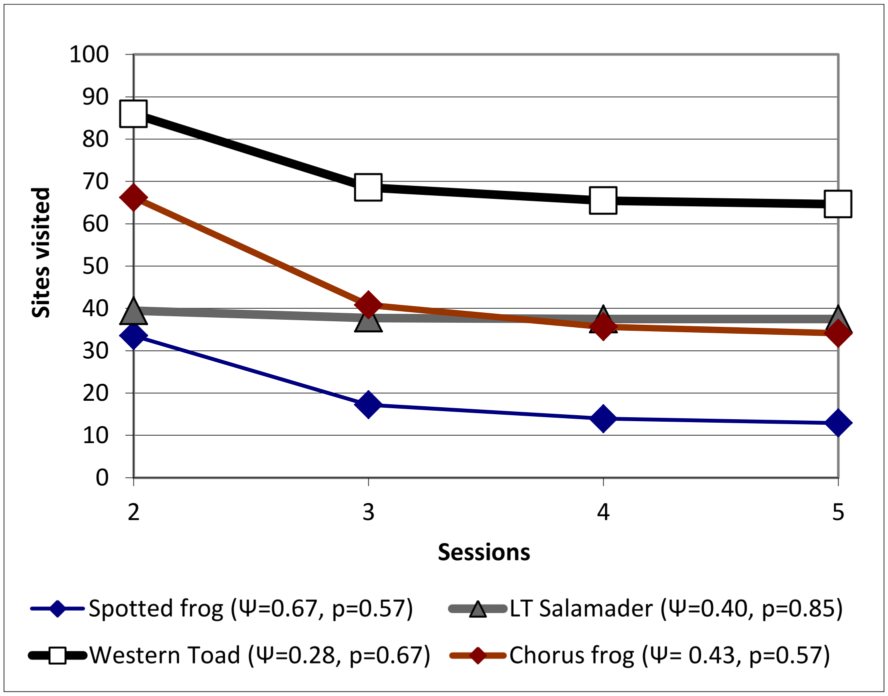

Figure 2: The number of sites and sampling sessions needed to obtain a point estimate of occupancy with a coefficient of variation of less that 20%. Occupancy rates (Ψ) are from Table 1 with values of detection probability (p) taken from other studies (Table 2). The occupancy for Long-Toed Salamander and Pacific Chorus Frog are from Kootenay Boundary and the rest are averaged across all 4 districts.

The detection rates used for the analyses in Figures 1 and 2 were uncertain given that they were based on other studies conducted in other regions (Table 2). Therefore, I considered various designs across a range of detection rates for the target species. For this analysis, occupancy was set at the average naïve levels in initial efforts (Table 1) and detection rate was varied (Figure 3).

In general, coefficients of variation from the designs with 4 sessions (2 visits) were less sensitive to detection rate compared to the design with 2 sessions (Figure 3). For example, a design with 40 sites visited for 4 sessions (2 visits with 2 independent observers) displayed a more consistent coefficient of variation of occupancy compared to a design with 80 sites only visited once (2 sessions).

For all species combined any of the designs would be sufficient given that the overall detection rate of at least one amphibian species is high, and the overall occupancy rates for all species was high also. Therefore, the optimal design for survey really depends on the need to obtain adequate estimates for target species such as the Western Toad.

For the Western Toad, that displayed lower occupancy (0.28), it was only possible to obtain occupancy estimates with a CV of less than 20% if 80 sites were visited for 4 sessions if detection rates of greater than 0.4. If only 2 sessions of sampling were conducted with 80 sites, then detection rates needed to be 0.7 or greater. With a 60 site design, the CV was close to 20% but not below 20% at any detection rate. It was not possible to obtain a CV of less than 20% if only 40 sites were visited (for the Western Toad). This result follows from MacKenzie and Royle (2005) who suggest that if a species displays low occupancy then it is better to visit more sites than add on more sessions whereas if occupancy is higher than it is possible to obtain adequate precision solely by adding more sites. One other way of conceptualizing this is that adding more sessions basically reduces the reliance of any design on having higher detection rates. But if a species is rare, it is essential that enough sites are sampled to allow an adequate sample size of occupied sites.

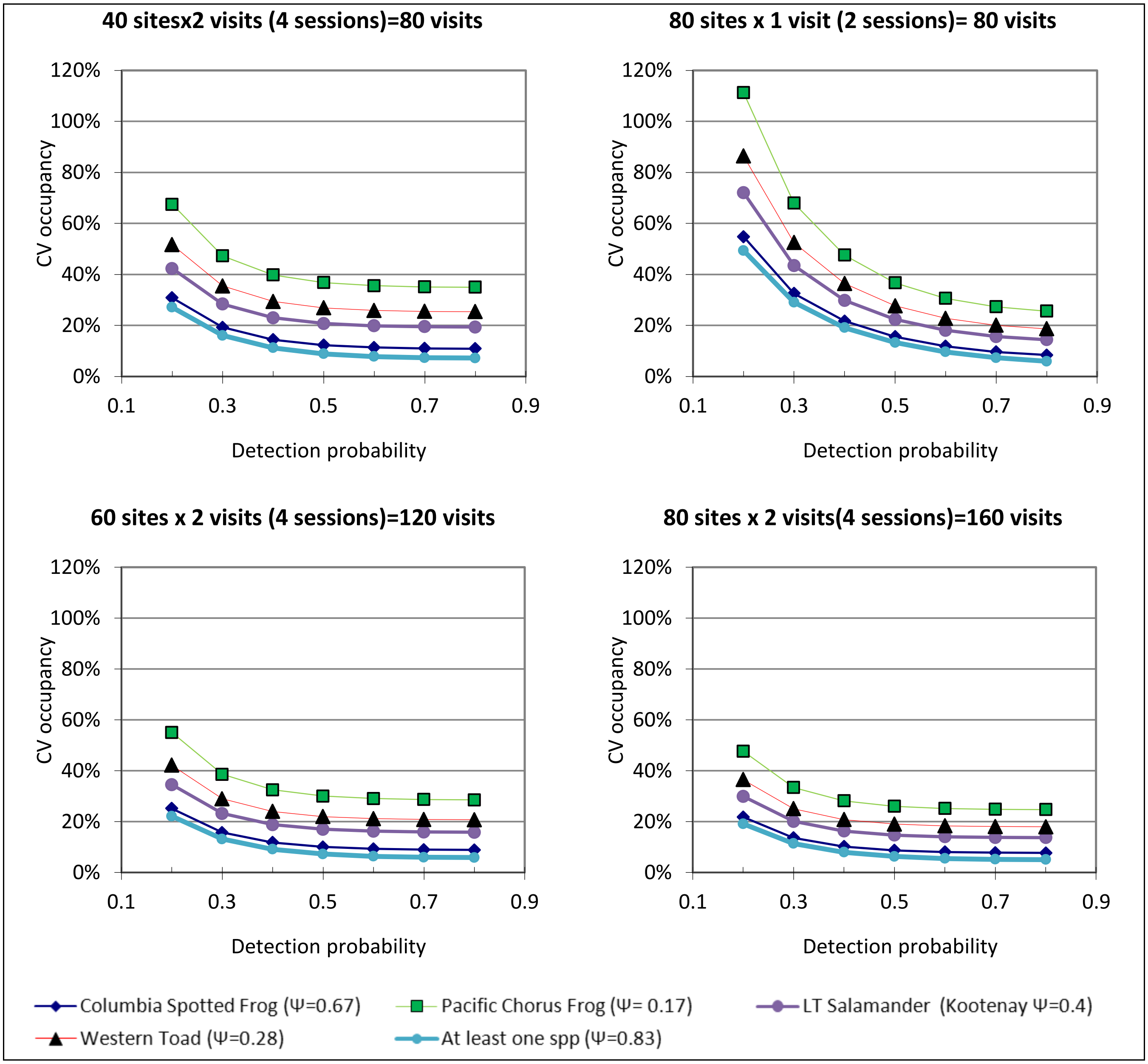

Figure 3: The relationship between occupancy and detection probability as a function of naive occupancy rates for the target amphibian species, and amphibian species pooled for 4 different sampling designs.

An alternative design that would potentially be viable for species such as the Western Toad that display low occupancy rates is a hybrid “Panel design” (Table 3) where a subset of sites is visited multiple times and another subset of sites is only visited once (for 2 sessions). The panel design differs from the double sampling design in Table 3 given that 2 sessions are conducted (using 2 independent observers) for all sites whereas only a single session of sampling is conducted (i.e. 1 observer) for some sites with the double sampling design.

To investigate the panel design further, I conducted a set of simulations in GENPRES that compared the precision of occupancy estimates for a design with 80 sites visited once, 80 sites visited 2 times, 60 sites visited 4 times, and a panel design with 40 sites visited once and 40 sites visited twice. For these simulations I set true occupancy at 0.28 (naive occupancy for Western toad in Table 1) and detection rates at 0.67 (lower range of detection probability from literature in Table 2). The results of simulations suggested that assuming these values the panel design displayed adequate precision that was intermediary between the 2 and 4 session standard 80 site designs and slightly better than the 60 site 4 session design. The advantage of the panel design is increased inference on temporal variation in detection rates (through repeat visits to a proportion of sites) and more “insurance” against lower detection rates while meeting the sample size of sites needed to obtain precise occupancy estimates if occupancy rates were low.

Table 4: Results of GENPRES simulations of standard versus panel designs for the Western Toad assuming true occupancy of 0.28 and a detection rate of 0.67.

Design	SitesxSessions	Visits	Occupancy	SE	CV
Standard	80x4	160	0.283	0.045	16.1%
Standard	80x2	80	0.286	0.069	24.0%
Standard	60x4	120	0.284	0.060	21.2%
Panel	40x2, 40x4	120	0.287	0.055	19.3%

For some species such as the Pacific Chorus Frog none of the designs resulted in a coefficient of variation of occupancy of less than 20% (Figure 3). I will note that the estimation of occupancy for the Pacific Chorus Frog may actually be higher if detection rates are lower and therefore these findings should be re-assessed when actual occupancy data is collected. If occupancy is lower then it may be optimal to restrict the analysis of the Pacific Chorus Frog to the Kootenay Boundary district or use covariates that describe the likely north-south gradient of Pacific Chorus Frog occurrence. If a suitable covariate is found then it may be possible to still obtain estimates of adequate precision since the covariate will explain variation in occupancy therefore reducing the overall error in the occupancy estimate.

Other factors affecting optimal study design.

There are other factors that should be considered beyond the precision of occupancy estimates. These general comments apply to both single season and multiple season occupancy projects.

Modeling of temporal variation in detection rates

Documentation and modeling of temporal variation in detection rates should be considered for the initial year of sampling. The information on how detection rates vary with weather, seasonality, and other factors would provide useful information to optimize sampling in subsequent years. To accomplish this, at least a subset of sites would need to be visited a minimum of twice to assess temporal variation (given that the independent observer method only considers spatial/observer variation and not temporal variation). It would still be possible to model temporal variation in detection rates if sites were only visited once (with two observers) but it would be likely that site-specific variation in detection rates and temporal variation in detection rates would be confounded. This topic is discussed in detail in Bailey et al. (2007).

Adequate sample sizes for modeling of covariates

One important objective of monitoring is not just estimating trends in occupancy but also determining environmental, biological, and other factors that may be driving changes in trend. The complexity of mark-recapture models is limited by the sample size of sites and detections at sites. In general, the maximum number of parameters in a model is approximately the effective sample size divided by 10. Effective sample size would be based mainly upon the number of independent sites as well as the number of sampling sessions. Therefore, a design that samples more sites should allow more ability to model both individual site covariates as well as temporal covariates that affect occupancy and detection rates. As a result, a 40 site design would only allow approximately four parameters in the mark-recapture models whereas an 80 site design would allow eight parameters and further simultaneous evaluation of the influence of covariates.

Occupancy models for monitoring; considerations for study design

The standard single season occupancy model estimates the probability of occupancy (Ψ) and detection probability (*p*). Occupancy models designed for multi-year monitoring also estimate the probability of extinction (ε) and probability of colonization (γ). Year-specific occupancy probabilities are related to extinction and colonization probabilities by the following equation:

$$\psi_{t+1} = \psi_t(1-\varepsilon_t) + (1-\psi_t)\gamma_t$$

Basically, occupancy for the next year (t+1) is determined by the sites occupied in the current year that do not go extinct ($\psi_t(1-\varepsilon_t)$) plus the number of sites not occupied that are colonized$(1-\psi_t)\gamma_t$. Therefore, the relative power and precision of any monitoring design depends on assumptions about both colonization and extinction rates.

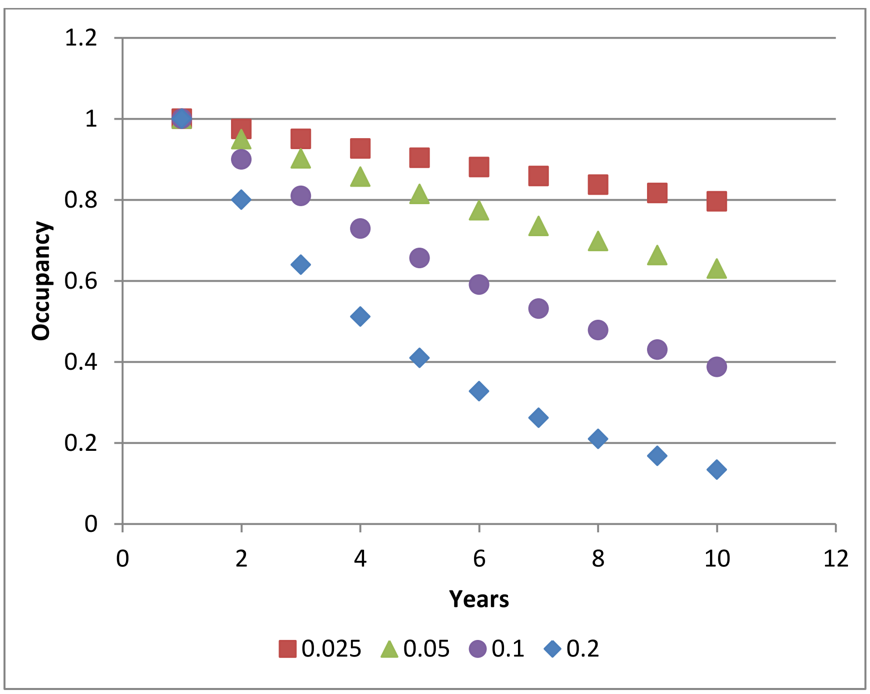

Figure 4: The relationship between occupancy and extinction rates as a function of years of monitoring.

The formulation of the monitoring occupancy model also provides some insight on optimal study design. Namely, if smaller declines in occupancy are anticipated then the actual difference in occupancy between subsequent years will not be great and in this context annual sampling would not be required. In fact, other simulation studies of mark-recapture sampling designs have demonstrated that once an initial data set is collected then there is minimal loss of power by going to bi-annual or tri-annual sampling designs (Boulanger 2005). A more detailed simulation study of designs could be used to explore this further.

In addition, eventual trends in occupancy should be considered when choosing the number of sites for initial efforts. In general, it is best to not increase the number of sites sampled over time given that trends in occupancy will then be influenced by both the new sites and trends in the previous sites. Therefore, if declines are anticipated then starting with a larger number of sites is an optimal strategy. For example, Western Toads were detected in 11 of 40 sites in the West Kootenay. If these sites were the sample size for initial efforts, and further occupied sites were not detected, and declines occurred, then the future sample size of occupied sites would become even lower making it more difficult to obtain precise occupancy estimates. In this case, starting with a larger number (80) sites is good insurance to ensure precise inference from future efforts.

Collection of adequate covariates

It is essential that covariates that affect both detection rates and occupancy be collected during field visits to sampling sites. Occupancy models assume that detection rates are similar between sites and therefore the collection of covariates that describe differences in detection rates is fundamental to unbiased estimation of occupancy. Many of these covariates have already been collected from previous sampling. However, particular attention should be given to covariates affecting detectability. For example, Pearl et al. (2009) found that the presence of fish, vegetation type, and year-specific influences (such as lack of precipitation in some years) affected the detectability of Western Toads. Hausleitner and Dulisse (2011) found that survey timing affected detectability of Columbia Spotted Frogs. In addition, sampling effort (i.e. length of transect sampled) should be standardized and any difference in sampling effort between sites should be noted. The relative abundance of amphibians can also affect detection rates as well as occupancy rates. There is also a class of occupancy models that directly considers counts rather than presence-absence data when estimating occupancy rates (Royle et al. 2005, Dorazio 2007). If data is suitable for this application, then unequal detection rates based on relative abundance can be directly accounted for in the modeling process therefore reducing bias in occupancy estimates.

I emphasize that it is through the collection of covariates that inferences about larger scale occupancy and trends in occupancy can be refined to the actual mechanisms that cause changes at the site level. Greater attention could be given to factors that might potentially influence occupancy but also extinction and colonization rates. For example, connectivity to other wetland areas, or barriers to movement between areas could affect both colonization and extinction rates. Therefore, greater assessment of landscape scale covariates should be considered when selecting sites for monitoring efforts so that future monitoring will sample the likely range of factors that might influence longer-term demography.

It may be of interest to determine if there are patterns in co-occurrence of two amphibian species or amphibian species and fish or other factors that are detected without certainty at sites. In this case, there are two sources of uncertainty, the presence of the amphibian and the presence of the other species. For this application, a multi-species occupancy model (MacKenzie et al. 2006) can be used to explicitly model how two species co-occur and factors determining the occurrence of each species in a single analysis. This approach will provide a more robust analysis if the determination of the presence of a given covariate is not certain.

Selection of sites to sample

The actual selection of sites to monitor will depend on the objectives of long-term monitoring. For unbiased occupancy estimation it is important to select a random sample of sites in the target study areas so that occupancy estimates represent overall trends in the study area. Assuming that the areas from the previous inventories are a random sample, a random sampling of the sites could be used to ensure that the selection of sites used for monitoring is random. Only sampling sites where detections have occurred will bias occupancy estimates since this will not be a random sample of all sites. In this case trends in occupancy may track the "survival" of sites known to be occupied. MacKenzie et al (2006) discusses one strategy where sites that were known to be occupied historically and unknown sites are stratified in trend analyses to test if the known occupancy sites are displaying trends compared to the unknown sites. This strategy may be reasonable for species such as the Western Toad where relatively few sites are known to be occupied (Table 1). For example, monitoring efforts may initially sample all sites where toads were known to occur to ensure a reasonable sample size of sites to track trends in occupancy for this species under the assumption that a main objective of monitoring is to track Western Toad status. In the eventual analysis trends could be tested with the known sites as a unique group therefore allowing a more precise extinction probability to be compared with unknown status sites. In addition, it may be reasonable to further stratify sampling based upon management districts, or well defined ecological criteria for stratification (i.e. ecotypes etc.) or covariates of interest that might affect trends in occupancy (i.e. pH of wetlands). For example, it may make sense to stratify initial sampling based upon forest district so each district received an approximately equal number of sites. However, whether stratification is needed in this case depends on whether an objective of the monitoring design project is to obtain specific occupancy trends for each district. Site selection should be conducted in a workshop format where exact study objectives can be discussed to further guide site selection.

Scale of sampling and inferences about occupancy

Original sampling efforts considered three regions for assessment of occupancy (Table 1). The determination of sample sizes (Figure 4) mainly considered one single area. Therefore, these recommendations apply to a single large study area rather than each region separately. The main question becomes whether district-specific estimates and trends in estimates are required. It would still be possible to test for differences in occupancy or trends in occupancy across forest districts by adding forest district as a group covariate in the analysis. For example, the relative support of a model that assumes similar occupancy and detection rates ($\Psi(.)\ p(.)$) could be contrasted with a model that has specific occupancy and detection rates for each region ($\Psi(\text{district})\ p(.)$). The district specific model would only require 2 more parameters compared to the model with pooled estimates of occupancy. Therefore, consideration of a larger study area does not preclude the estimation and modeling of region specific occupancy. However, if district-specific rates are required then a design with a larger number of sites (i.e. 80) would be favoured over a design with a smaller number of sites and more sessions to ensure adequate coverage of all areas.

Estimation of breeding site encounter rates

One other objective of monitoring efforts was the estimation of breeding site encounter rates. In the context of occupancy sampling, the optimal way to do this would be to use a multi-state occupancy model where each site is categorized into three states; no detections, non-breeding amphibians detected, and breeding amphibian species detected (MacKenzie et al. 2006). This approach would allow estimates of occupancy as well as relative change in each of the states to be modeled over time. For example, it could be hypothesized that changes in climate might cause some amphibian species to have reduced breeding activity. In this case, it would be expected that occupancy rates of the breeding state would decrease but the non-breeding state may not decrease over time. In addition, it may be likely that the non-breeding state is easier to detect than the breeding state. Subsequently, detection probabilities could be estimated for each state. I would suggest that at least two visits are conducted for at least a subset of sites if this type of analysis is to be used. The reason for this is that it is likely that there is temporal variation when breeding states can be detected which might vary on a site-by-site basis dependent on factors such as altitude and micro-climate. However, multiple visits to the sites would capture this type of variation for subsequent analyses.

Synthesis of findings and recommendations

This report provides general guidelines for the adaptive design of a multi-year monitoring program of amphibian occupancy. One important trend to note in Figure 4 is the sensitivity of the precision of occupancy estimates to detection probability especially for species that display lower levels of occupancy. This general trend would also be apparent with power analyses of monitoring designs. For example, naïve occupancy estimates are the product of true occupancy and detection rates. If detection rate is low then it is possible that the naïve occupancy estimate will under-represent true occupancy. If the negatively biased naïve occupancy was then used to design longer-term projects it would be likely that a design that favoured having more sites would be designed when actually it would be more important to conduct more sampling sessions. Given this, it is essential that an initial year of data on both occupancy and detection probabilities are collected to allow a more informed assessment of optimal longer-term monitoring strategies.

I suggest that the initial year of data collection should be designed as an initial year of trend monitoring rather than a reduced "pilot study" given that adequate baseline data already exists for the target study area(s) (Table 1). The designs that were proposed for the initial year of sampling should be adequate to allow further sampling for trend with the same general design and perhaps less sampling effort in subsequent years. The general strategy behind this approach was used to optimize amphibian surveys in Yellowstone Park (Bailey et al. 2007). In this case, a simulation study was used to ensure that both an optimal number of sites and an optimal number of sessions were used in subsequent years of sampling to allow inference about occupancy as well as extinction, colonization rates and the influence of covariates on occupancy parameters.

Table 5: Summary of recommendations categorized by initial objectives of the monitoring program

Objective	Recommendations
Detect changes in occupancy	**General method**: *Conduct initial year with a study design that assures a CV<20% of occupancy estimates for all species. Use this data to further refine sampling strategy (Table 3) through the use of focused simulation modeling.*
a) Coarse scale-all species	**Initial year**: *All designs in Figure 4 would suffice given the overall high levels of occupancy and detection rates for all amphibian species pooled. Spatial variation could be assessed for the initial year using covariates*.
b)Species-specific scale	**Initial year**: *A hybrid panel design where 40 sites are visited twice and 40 sites are visited once (80 sites total) provides a good compromise between replication of sites and the need to visit many sites for species with lower occupancy such as the Western Toad.*
	Subsequent years: *Further simulation modeling of data from the initial year of sampling will be used to further refine sampling intervals and design. Change in occupancy will be further investigated by estimation of extinction and colonization rates.*
Determine magnitude of change	*Collection of covariates and use of the robust design occupancy model.*
a) Assess scale of change	*Modeling of district-specific, region-specific, or ecotype specific covariates in eventual trend analysis data set*
b) Cause of change	*Modeling of individual site covariates with an emphasis on covariates that influence extinction and colonization rates.*
Breeding site encounter rate	*Multi-state occupancy models can be used that allow categorization of sites as breeding and non-breeding to allow different detection rates and assessment of causes of change of breeding status of sites.*

In any case, I recommend a double observer method where two independent observers visit sites so that two sessions of sampling can be conducted in one visit. This method is optimal given that a great deal of the cost is transportation to field sites. If inference on the Western Toad is of key interest then a design with 80 sites visited for 2-4 sessions is suggested. While the two session design may be sufficient if detection rates are high, the 4 session design provides additional insurance since occupancy estimates will be less sensitive to lower detection probabilities and will provide more inference on temporal variation in detection rates. A hybrid "panel" design (Bailey et al. 2007) that visits 40 sites twice and 40 sites once (with two independent observers) provides a potential compromise between replicate visits and the need to visit many sites if budgets and logistics limit an 80 site-4 session (visits) design.

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