## Relative Abundance, Detection Probability, and Power to Detect Population Trends of Marsh Birds in North America


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## Introduction

The acreage of emergent wetlands in North America has declined sharply during the past century (Tiner 1984, Dahl 2006). Populations of many marsh birds that are dependent on emergent wetlands may be adversely affected, but we currently lack adequate monitoring programs to determine status and estimate population trends at large spatial scales. Primary species of concern in North America include King Rails (Rallus elegans), Clapper Rails (Rallus longirostris), Virginia Rails (Rallus limicola), Soras (Porzana carolina), Black Rails (Laterallus jamaicensis), Yellow Rails (Coturnicops noveboracensis), American Bitterns (Botaurus lentiginosus), Least Bitterns (Ixobrychus exilis), Pied-billed Grebes (Podilymbus podiceps), Limpkins (Aramus guarauna), American Coots (Fulica americana), Purple Gallinules (Porphyrula martinica), and Common Moorhens (Gallinula chloropus). The U.S. Fish and Wildlife Service identified Black Rails, Yellow Rails, Limpkins, and American Bitterns as Birds of Conservation Concern (U. S. Fish and Wildlife Service 2002). King Rails (endangered) and Least Bitterns (threatened) are federally listed in Canada and Black Rails are federally endangered in Mexico. Furthermore, several rails are game birds in many states and provinces (Tacha and Braun 1994).

For these reasons, efforts have been underway for the past decade to develop continental survey protocols for North America (Ribic et al. 1999, Conway and Gibbs 2001, Conway and Timmermans 2005, Conway and Droege 2006). The continental survey protocols (Conway 2008) have been used on many National Wildlife Refuges (NWRs) and at a variety of other locations in North America over the past 8 years. Numerous methodological questions related to optimal survey design were raised at a recent marsh bird symposium (U.S. Fish and Wildlife Service 2006). This project was an attempt to address some of these lingering questions by analyzing the existing survey data. The goals of this project were to address the 6 specific objectives outlined below.

Objective \#1: Conduct a power analysis to determine sample size requirements to estimate population trends for each of several marsh bird species at several spatial scales.

Designing efficient monitoring programs requires balancing trade-offs in the cost of data collection against the risk of failing to detect meaningful changes in population parameters. Several strategies are available for exploring alternative sampling designs, one of which is statistical power analysis. In the context of monitoring, statistical power $(1-\beta)$ is the probability of correctly detecting a temporal trend in a parameter. Power is the complement of committing a Type II error ( $\beta$ ), or failing to detect a real trend in a population parameter. If the undetected trend is negative, consequences for species of conservation concern may be consequential.

Power is a function of sample size, variation in the sample data, the true size of the trend in the population parameter, the statistical test used, and the probability of
committing a Type I error ( $\alpha$ ), that is, mistakenly claiming a trend exists (Steidl et al. 1997). Alternative sampling strategies can be explored and compared through their consequences on estimated power by varying levels of factors that are under the control of investigators. The basic approach is to estimate power for a range of design alternatives and use power estimates to guide decisions as to which combinations are most effective in light of other considerations, such as sampling costs. Practically, power analysis is a platform for exploring design alternatives so that a monitoring program can be established where the risk of committing a Type II error is small, thereby minimizing mistakes most relevant to conservation.

## Methods - Objective \#1

We used count data collected at NWRs for 7 species of marsh birds to estimate the power of these efforts to detect a linear trend for periods of 2 to 30 years. The number of refuges used in analyses varied by species and ranged from 26 to 83 . Because we cannot know the size of the trend in advance, we estimated power for trends of $1 \%, 3 \%$, and $5 \%$ per year, and fixed the Type I error rate at $\alpha=0.05$. We explored how variation in sampling effort (number of refuges and survey points) affected power where 1 ) all refuges were sampled annually, and 2) refuges were sampled every other year (i.e., half of the refuges sampled 1 year, the other half sampled the subsequent year).

We partitioned the total variation in counts into 4 components (Larsen et al. 1995, Kincaid et al. 2004; Table 1):

1. population variance (NWR): variation among refuges;
2. year variance (Year): year-to-year variation not attributable to a trend;
3. refuge-year interaction (NWR*Year): variation due to local effects;
4. index or residual variation: (Error).

To estimate variance components for each of the 7 species, we used a subset of all available data that included refuges that were sampled for a minimum of 3 years where the species under consideration was detected at $\geq 1$ survey point. We also restricted the dataset by: 1) excluding data for species whose calls were not included in the broadcast sequence at each point, 2) excluding birds detected at a previous survey point, 3) excluding data for surveys that were conducted outside of the typical breeding season (15 March - 15 July), and 4) including data from only one observer for surveys that were conducted as multiple-observer surveys. Based on these components of variation, we computed estimates of residual mean square error (RMSE). We assumed that variation in counts not explained by any existing trend would remain constant over time. Estimates of RMSE are a key element of power in this context. When RMSE is relatively low, power to detect trends will be relatively high (and vice-versa), as the ability of a monitoring program to detect a trend depends on the consistency of counts among years.

As the response variable for estimating power, we used the average number of individuals of each species counted across all visits to the same survey point in a given year. This variable had $5-27 \%$ less total variation than counts from individual visits (Table 2).

We estimated power based on the assumption that temporal trends in logtransformed counts of birds per survey point (BPS) would be approximately linear. Trends in absolute abundance are unlikely to remain linear over long time periods because if the trend is constant (e.g., $2 \%$ per year), then the associated changes in raw abundances will vary over time. For example, if we assume that abundance $(N)$ is declining at a constant rate of $10 \%$ per year and that $N=100$ at time $t=0$, then at $t=1$, $N=90$ (a loss of 10 individuals) and a $t=2, N=81$ (a loss of 9 individuals). Therefore, the change in abundance over time under a constant rate of change will be logarithmic, not linear (Hayes and Steidl 1997). An additional advantage of this approach is that regression slopes correspond directly to the rates of change in the population. For example, a slope of 0.03 indicates a rate of change of $3 \%$ in abundance. Therefore, we report estimates of power for assessing potential trends in logarithmic number of birds counted per point.

Assuming we have an interest in detecting both increases and decreases in a parameter (i.e., both negative and positive population trends), the power ( $1-\beta$ ) of a statistical test for trend (slope) is:

$$
1-\beta=1-F_{t}\left(t_{1-\alpha / 2, d f}, \eta\right)+1-F_{t}\left(t_{\alpha / 2, d f}, \eta\right)
$$

where the $F_{t}(x, d f, \eta)$ is the cumulative distribution function of the noncentral $t$ distribution with $d f$ degrees of freedom, and noncentrality parameter $\eta$, evaluated at $x$ and $\mathrm{t}_{\gamma, \text { df }}$ which is the $100 \gamma \%$ quantile from a central $t$ distribution with $d f$ degrees of freedom.

We estimated power to detect temporal trends in species of marsh birds at the national level and at the regional level. At the national level, we computed power based on the total number of refuges that detected $>1$ individual of the species of interest and the overall average counts of birds per species per survey point (BPS), generated from the same subset of data we used to estimate variance components (Table 3). At the regional level, we computed power for 4 values in all combinations: the minimum and maximum number of refuges and the minimum and maximum average counts of birds per point for all regions (Table 4). These values represent the range of conditions present at the various U.S. Fish and Wildlife Service regions (1-6). Refuges in a particular region can then examine power values for different relevant scenarios and consider which values best match circumstances in their region. We assumed that the national data provided the most reliable estimates of variance components so we used these for power computations at both the national and regional scales.

We included a target of power $=0.80(\beta=0.20)$ as a common minimum target for monitoring programs. Nonetheless, this is arbitrary and higher standards are always better for conservation alternatives. Another approach would be to set $\beta=\alpha$, balancing the 2 potential errors, which would suggest a target of power $=0.95$.

## Results - Objective \#1

## National level

Power to detect national trends in abundance of American Bitterns, Clapper Rails, and Virginia Rails increased markedly as the number of points sampled
increased; although the benefit of sampling more points decreased as the number of years sampled increased (Appendices 1-2). In general, power increased greatly after 510 years of sampling.

Increasing the number of points had little effect on the power to detect nationwide trends for King Rails, Least Bitterns, Pied-billed Grebes, and Soras (Appendices 12). For these species, power to detect a $1 \%$ trend was less than the target value even after 30 years of sampling. Power to detect a 3\% or $5 \%$ trend exceeded the target value, but this occurred only after 10-20 years of survey data. Gibbs and Melvin (1997) also reported low power to detect a $1 \%$ annual change but sufficient power to detect $>2 \%$ annual change for some of these same species after 10 years of sampling.

As expected, sampling biannually reduced power when compared to sampling annually, but in general the decrease was relatively small (Appendices 1-2). The reductions in effort and cost for biannual sampling may provide an acceptable trade-off provided sampling continues for many years.

## Regional level

Abundance of a species (BPS) had a large effect on power, and often a larger effect than the magnitude of the trend or the number of years sampled (Appendices 12). When abundances were very low (InBPS < 0.01), power often remained low even after 30 years of sampling, with large trends, or with a large number of refuges sampled (e.g., King Rail, Least Bittern in some regions). For some regions, abundance was substantially higher (3-4 times) than the national average which resulted in higher power to detect trends at the regional level than at the national level (e.g., Clapper Rail, Piedbilled Grebe). Increasing the number of refuges surveyed also improved power, but adding refuges for species with low abundances (e.g., King Rail, Least Bittern, and Sora in some regions) may not sufficiently overcome the influence of low abundances on power to detect trends.

## Overall

The number of sampling locations and the number of years sampled are important elements of virtually all monitoring efforts because they directly affect power of the monitoring program. Obviously, power to detect trends will always be higher when sampling intensity is higher and when surveys are conducted over a longer period of time. The number of refuges and the number of points sampled also influence power, but the magnitude of this effect depends on the relative amount of variation captured in the different variance components. For example, if data from different refuges varies greatly in comparison to the other variance components, increasing the number of refuges sampled will likely greatly increase power to detect trends (e.g., Clapper Rail).

Although not under investigator control, abundance has a large influence on power. The power to detect trends is low for rare species, but these are the species for which we typically are most interested in obtaining trend estimates. Obtaining reliable trend estimates for rare species with inherently low abundances will require more years of sampling compared to the more abundant species. Low power does not guarantee that a trend in populations of these species will not be detected; detection is just less likely. In other words, power estimates and statements about design alternatives are
inherently probabilistic. Therefore, the outcome for a future trend assessment based on a particular combination of design alternatives can never be known with certainty.

## Objective \#2: Estimate relative abundance for each of several species of marsh birds at several spatial scales: refuge, region, and national.

A measure of relative abundance for each species of marsh bird would provide insights to NWR staff regarding which refuges harbor the highest densities of each species. This information is useful for targeting management efforts and developing comprehensive conservation plans. This information will also help individual refuges examine how their refuge likely contributes to the persistence of each species relative to other refuges within their region. For this analysis, we only included data from 1 observer for surveys that included data from multiple-observer surveys. We did not exclude detections of birds that observers thought they detected at a previous point and birds that were detected while observers traveled between survey points. For each species, we calculated the average number of individuals detected per point-count survey on each of 73 refuges. We calculated more than one mean for refuges that used more than one broadcast sequence. We did not want to pool data across broadcast sequences because the sequence used determines the duration of the survey at each point. Refuges used more than 1 broadcast sequence for 1 of 2 reasons: 1) they used different broadcast sequences on different survey routes (e.g., 1 for freshwater marshes on their refuge and another for saltwater marshes on their refuge), or 2) they changed their broadcast sequence after 1 or more years of conducting surveys to eliminate species that were not present (and hence shortened the time surveyors spent at each point).

For each broadcast sequence at each refuge, we only included an average number detected for species that: 1) were included in that call-broadcast sequence at that refuge, or 2) were detected even though their calls were not included in that broadcast sequence. We included averages for species that were detected but not broadcast (\#2 above) because some refuges recorded American Coots even though they did not include coots in their broadcast sequence, and some refuges detected species that they were not aware were present when they requested their broadcast sequence. However, numbers in Table 5 for species at refuges that did not broadcast that species' call should be interpreted with caution as surveyors may have only recorded visuals or only occasionally recorded that species during surveys. We also calculated an average for each species within each region, and an average for each species across all refuges across the country. These regional and national averages allow individual refuges to examine whether they have higher relative densities of each species compared to the regional or national average.

## Results - Objective \#2

The relative abundance of most species of secretive marsh birds was low; mean number detected was $<0.3$ birds per point at $>75 \%$ of the 73 refuges for all species except Clapper Rails, Pied-billed Grebes, Common Moorhens, and American Coots (Table 5). This is not surprising given that rarity is 1 of the main reasons that these species have been underrepresented in other survey efforts. The relative abundance of all species varied greatly among refuges, and all species had high relative abundance
at a few refuges and low relative abundance at many refuges (Table 5). This pattern of high relative abundance in a small portion of a species' range and low relative abundance in the majority of their range is common among species of birds (Brown et al. 1995). Some of the variation in relative abundance among refuges is undoubtedly due to variation in: 1) the observers' ability to detect the often faint calls of many of these species, 2) the duration of the surveys (which varied from 6-14 min per point), and 3 ) the broadcast sequence used on each refuge ( 67 different broadcast sequences were used; Table 5). Relative abundance differed among species; Yellow Rails and Black Rails were rarely detected (e.g., all but 3 locations that broadcast Black Rail calls had $\leq 0.10$ birds detected per point), whereas Clapper Rails, American Coots, and Piedbilled Grebes were more abundant throughout their range. Relative abundance varied among regions for most species; American Bitterns were most abundant in Regions 1, 3, 4, and 8, American Coots were most abundant in Regions 1 and 2, Black Rails and Virginia Rails were most abundant in Region 2, Clapper Rails were most abundant in Regions 4 and 8, King Rails were most abundant in Regions 2 and 4, and Common Moorhens, Least Bitterns, and Pied-billed Grebes were most abundant in Regions 2 and 8 (Table 5). Compared to the other species, the number of Soras detected per point was less variable among regions (except for low abundance in Region 5). Refuges with the highest relative abundance for each species (in decreasing order of abundance) were:

Black Rail: Imperial NWR, Bill Williams NWR
Least Bittern: Imperial NWR, Havasu NWR, Cibola NWR
Yellow Rail: Rice Lake NWR, Great River NWR
Sora: Horicon NWR, Agassiz NWR, Medicine Lake NWR
Virginia Rail: Bitter Lake NWR, Stewart B McKinney NWR, Nisqually NWR, Imperial NWR
King Rail: Mackay Island NWR, Ten Thousand Islands NWR, Mattamuskeet NWR
Clapper Rail: Eastern Shore of Virginia NWR, Sonny Bono-Salton Sea NWR, Martin NWR
American Bittern: Bear Lake, Agassiz NWR
Common Moorhen: Merritt Island NWR, Havasu NWR
Purple Gallinule: Bon Secour NWR, Aransas NWR
American Coot: Bosque del Apache NWR, Turnbull NWR, Camas NWR
Pied-billed Grebe: Mud Lake WMA, Medicine Lake NWR, Bosque del Apache NWR, Imperial NWR
Limpkin: Ten Thousand Islands NWR (the only participating refuge that had Limpkins)
Ranking of refuges based on relative abundance like this must be interpreted cautiously because: 1) the numbers detected were influenced by when surveys were conducted (some refuges may not have conducted their surveys during the optimal stage of the nesting cycle), 2) the ability of the surveyors likely varied greatly among refuges, and 3) only a very small portion of the marshlands available on a refuge were surveyed at most refuges.

Objective \#3: Analyze detection rate differences at local and regional levels with passive and broadcast calls. In particular, determine why call-broadcast appears to increase numbers of American Bitterns detected at some local scales, but not at the continental scale.

We used pooled data from NWRs to compare the percentage of American Bitterns that were detected during each 1 -min segment of marsh bird surveys. In particular, we compared the percentage of birds that were detected during the 1 -min segment that included American Bittern calls to the 51 -min passive segments. We first used all available data that was collected as part of the National Marsh Bird Monitoring Program (Conway 2008) that included data recorded during 1 -min segments. This was similar to the analysis in Conway and Nadeau (2006) but included additional data (2001-2006). We also conducted these same analyses on subsets of the data to determine whether call-broadcast was more effective at increasing detection of American Bitterns within certain regions or at specific localities. At a regional scale, sufficient data on American Bitterns was available for 3 FWS regions (R1, R3, and R6). At the local scale, sufficient data on American Bitterns was available for 4 specific localities (Bear Lake, Agassiz NWR, Red Lake Chippewa Lands, and the Prairie Pothole region). One covariate that might influence whether or not call-broadcast influences detection probability is distance from the bird to the surveyor. American Bitterns are often detected at great distance during surveys and call-broadcast may only be effective at increasing vocalization probability for birds that are relatively close to the broadcast source. Hence, we examined the effects of call-broadcast on detection probability of American Bitterns using a subset of the data that included only birds that were $\leq 100 \mathrm{~m}$ from the surveyor.

## Results - Objective \#3

We were able to include data from 3216 American Bitterns detected during surveys across North America. The percentage of these American Bitterns that were detected during the 1-min call-broadcast segment that included American Bittern calls (41.2\%) was only slightly higher than the percentage that were detected during any of the 5 1-min passive segments (33-38\%; Fig. 1). Our results were similar when we examined data from specific regions (Fig. 1b-d) although call-broadcast did appear to increase detection probability slightly more in Region 3; the percentage of American Bitterns that were detected during the 1-min call-broadcast segment that included American Bittern calls (40.4\%) was slightly higher than the percentage of American Bitterns that were detected during any of the 51 -min passive segments (32-37\%; Fig. 1c). Our results were also similar when we examined results from specific localities; call-broadcast appears to increase detection probability of American Bitterns only slightly (Fig. 2). We also included the percentage of American Bitterns that were detected during the broadcast of other species. The sample sizes for each of these 1min call-broadcast segments were less than 3216 because the broadcast sequence differed at each specific location and for this analysis we examined all American Bitterns that were detected during surveys that included American Bitterns in the broadcast sequence. Hence, the percentage of American Bitterns detected in the 1-min segments involving other species' calls in Figs. 1-2 should be compared with caution, especially for those segments where the sample size was substantially lower than 3216. But, we
see no evidence that detection probability of American Bitterns is reduced due to the broadcast of other species' calls.

When we restricted our analysis to the 938 birds that were detected $\leq 100 \mathrm{~m}$ from the surveyor, we observed stronger evidence that call-broadcast increases detection probability of American Bitterns; 45.2\% of the 938 birds were detected during the 1-min segment of American Bittern call-broadcast whereas 36-40\% of the 938 birds were detected during the 5 passive 1-min segments (Fig. 3). The results were similar when we restricted our analysis to birds that were $<75 \mathrm{~m}$ and $<50 \mathrm{~m}$ from the surveyor. When we analyzed data separately by month, the effects of call-broadcast were fairly similar but appeared a bit more noticeable during April and May compared to June.

Many participants used a 5-min call-broadcast sequence. So we conducted a similar analysis on just those surveys that had a 5-min call-broadcast sequence and the sequence included American Bittern calls. For this subset of surveys, we compared the percentage of American Bitterns detected during the entire 5-min passive segment to the percentage detected during the entire 5-min call-broadcast segment. Of the 1641 American Bitterns detected, $78.1 \%$ were detected during the 5 -min passive segment and $82.4 \%$ were detected during the 5 -min call-broadcast segment.

## Objective \#4: Determine whether or not birds have a "delay' or "lag" in response to call-broadcast.

Marsh birds may wait for $\geq 1$ min after hearing conspecific broadcast before they vocalize (Bogner and Baldassarre 2002). If such a "lag" in response to call-broadcast is common, this can help inform development of effective survey protocols. For example, we may be missing the benefit of call-broadcast for species' whose calls are usually last in the call-broadcast sequence if a lag in response is common. Evaluating whether or not a lag in response is a common problem is difficult with existing data because current protocols (Conway 2008) instruct surveyors to broadcast calls in the same chronological order throughout North America. Hence, smaller and less-abundant species (e.g., Black Rails and Least Bitterns; see Objective \#2) are always early in the broadcast sequence and larger and more-abundant species (e.g., Clapper Rails, American Bitterns, Common Moorhens) are always near the end of the broadcast sequence. Detection probability is always highest during the 1 minute of conspecific call-broadcast, but detection probability during subsequent 1-min segments (when other species' calls are being broadcast) is usually higher than any of the 5 1-min passive segments (Conway and Nadeau 2006). This pattern could be caused by 1 (or both) of the following different mechanisms: 1) vocalization probability of most marsh birds is enhanced by hearing calls of other species of marsh birds, or 2) many birds wait >1 min to vocalize after hearing conspecific calls broadcast. In an effort to determine which of these 2 mechanisms is most likely, we tested the following predictions: 1) the percentage of birds detected will increase during the 1-min of conspecific calls and then will decrease gradually with each additional minute of the broadcast sequence (when other species' calls are being broadcast), 2) call-broadcast will be less effective at increasing detection probability for a species when that species' calls are last rather than first in the broadcast sequence.

We used data on Least Bitterns detected at 14 locations across North America that used call-broadcast sequences with the following attributes: 1) had LEBI calls in the
broadcast sequence, and 2) had $\geq 4$ species' calls that followed LEBI calls in the broadcast sequence. For each location, we summarized the percentage of Least Bitterns detected during each of the 5 1-min passive segments, during the 1-min of Least Bittern broadcast, and during each of the 41 -min broadcast segments that immediately followed the Least Bittern broadcast. The 4 species that followed Least Bittern in the broadcast sequence were not the same for the 14 locations. For example, Yellow Rail, Sora, Virginia Rail, and King Rail calls each immediately followed Least Bittern calls in the broadcast sequence for at least 2 of the 14 locations. The percentage of Least Bitterns detected during the 1-min of conspecific calls was higher than the percentage detected during any of the 1-min passive segments (suggesting that call-broadcast increases detection probability) (Fig. 4). The percentage declined with the subsequent species in the broadcast sequence, but was still higher than the percentage detected during any of the 1-min passive segments. However, we failed to see a gradual decrease with each additional minute of the broadcast sequence (when other species' calls were being broadcast). We believe that these results suggest that calls of other marsh birds increase detection probability of Least Bitterns (relative to passive surveys) rather than a lag in responsiveness of Least Bitterns to conspecific calls (see Objective \#5).

We used data for American Bitterns from 8 different locations in North America. Surveyors at these 8 locations all used a 7 -min broadcast sequence that included American Bittern. However, the order of the American Bittern's calls in the 7-min sequence varied among locations from $4^{\text {th }}$ to $7^{\text {th }}$ (last). If marsh birds often delay their response to conspecific call-broadcast, we should observe less benefit of call-broadcast for American Bitterns at those locations where the AMBI calls were at the end of the sequence. However, the 7-min call-broadcast segment was equally (if not more!) effective at increasing detection probability of American Bitterns in comparison to the 5min passive segment when AMBI calls were broadcast during the final $\left(7^{\text {th }}\right)$ minute of the broadcast sequence (Fig. 5).

We also tested this prediction experimentally on Clapper Rails by conducting 2 types of surveys in marshes in southwestern Arizona and southeastern California that were identical in all but 1 way: whether Clapper Rail calls were first or last in the broadcast sequence. One broadcast sequence had this sequence: BLRA, LEBI, VIRA, CLRA and the other broadcast sequence had this sequence: CLRA, BLRA, LEBI, VIRA. We conducted paired comparisons with these 2 sequences; surveyors would use the CLRA-first sequence on 1 visit and the CLRA-last sequence on the other visit to the same survey routes. We alternated which sequence was used first and we conducted both surveys within 48 hours an each survey route. For both of the broadcast sequences, $70-80 \%$ of the Clapper Rails were detected during the 4-min call-broadcast segment whereas only $40-50 \%$ of the Clapper Rails were detected during the $5-\mathrm{min}$ passive segment (despite being 1 min longer). This suggests that call-broadcast increased detection probability of Clapper Rails substantially over passive surveys. However, we observed no difference in the effectiveness of call-broadcast between the 2 broadcast sequences; call-broadcast increased detection of Clapper Rails in an equal manner regardless of whether Clapper Rails calls were first or last in the 4-min broadcast sequence (Fig. 6).

## Objective \#5: Determine which species respond interspecifically (i.e., respond to other species' broadcasted calls).

The use of call-broadcast during surveys has both benefits and drawbacks (Conway and Gibbs 2005). Most efforts to evaluate call-broadcast have focused on the effects of conspecific calls in isolation (Conway and Gibbs 2001). However, before we institutionalize the use of call-broadcast into a multi-species continental survey effort, we need more information on the effects of broadcasting numerous species calls on detection probability of the focal species. To evaluate the extent to which each species responds to the broadcast of other species' calls, we compared the proportion of individual birds detected during each 1 -min segment during surveys (i.e., of the total number of Black Rails detected, what proportion of those were detected during each 1min segment of the survey). We restricted our analysis to only include data from locations throughout North America that recorded data in 1-min segments and included a 5 -min passive segment. We further restricted our analysis to surveys conducted between March and July, and we excluded individual birds that were detected outside of the survey period (i.e., those detected before or after the official survey period at each point). We had sufficient data for 13 species of focal marsh birds. For each species, we only used surveys for which that species' calls were included in the broadcast sequence. We did not report proportions for any 1-min broadcast segments for which we had <60 detections (indicated by the lack of a bar in the panels in Figs 7-10). For each species, we used chi-square tests to compare the proportion of birds that responded during each 1 -min of the broadcast segment to the proportion of birds that responded during 1 -min of the passive segment (the average among the 51 -min passive segments). We also used the following formula to calculate the percent increase in number of birds during the 1 -min conspecific broadcast (relative to 1 -min of passive surveying): ((number of birds detected during the 1 min conspecific broadcast segment - average number of birds detected during a 1-min passive segment)/ average number of birds detected during a 1 -min passive segment).

All species were more likely to respond during broadcast of conspecific calls than during passive segments or during broadcast of interspecific calls (Figs. 7-10). Moreover, most species were more likely to respond during broadcast of 1 or more interspecific calls than during any of the 51 -min passive segments. Yellow Rails and Soras were more likely to respond during Virginia Rail calls (compared to the 1 -min passive segments), Clapper Rails were more likely to respond during Sora and Virginia Rail calls, Purple Gallinules and American Coots were more likely to respond during Pied-billed Grebe calls, Pied-billed Grebes were more likely to respond during Purple Gallinule calls, and Virginia Rails and King Rails were more likely to respond during broadcasts of most of the other species' calls (Figs. 7-10). Common Moorhens, American Bitterns, and Wilson's Snipe appeared to be unaffected by broadcast of interspecific calls; the likelihood of being detected during all of the 1-min interspecific broadcasts was similar to that during the 1 -min passive segments. The percent increase in number of birds detected as a result of conspecific broadcast varied among species: $101 \%$ for BLRA, $36 \%$ for LEBI, 112\% for YERa, 217\% for SORA, $439 \%$ for VIRA, 302\% for KIRA, 111\% for CLRA, $78 \%$ for COMO, $632 \%$ for PUGA, $58 \%$ for AMCO, 14\% for AMBI, 124\% for PBGR, and 18\% for WISN.

For each species in the analysis above, the sample sizes for most of the 1-min interspecific call-broadcast segments were less than the sample sizes for the 1-min conspecific call-broadcast segment and the 5 passive segments because the broadcast sequence was not the same at each location (but always contained 5 1-min passive segments and 1 min of conspecific calls). For example, our analysis included 180 Black Rail detections, but only 162 of those detections occurred at locations where Least Bittern calls were included in the broadcast sequence (Fig. 7). Hence, differences in the proportion of birds detected during interspecific and conspecific segments may be due (at least partly) to regional differences in density or response rate. To address this, we also did the same comparison separately for 4-5 broadcast sequences for which we had the most data for 3 species: Least Bitterns, King Rails, and Clapper Rails. When we examined data separately for the individual broadcast sequences for which we had the most data, these 3 species still were more likely to respond to conspecific calls than interspecific calls for most broadcast sequences (Figs. 11-13). But these 3 species were also more likely to be detected during many of the 1-min interspecific segments than the 5 passive segments, even some of the interspecific segments that occurred prior to the conspecific segment (Figs. 12-13). These graphs also allow us to look for evidence of a "lag" (Objective \#4); some suggested that a lag may exist (Figs 11a, 11b, 12a, 12d, 13b), but others suggested no evidence for a lag (11d, 12e, 13c).

Numerous past studies have reported that marsh birds vocalize more frequently in response to conspecific broadcasts compared to interspecific broadcast sequences (Tacha 1975, Johnson and Dinsmore 1986, Gibbs and Melvin 1993, Allen et al. 2004, Conway and Nadeau 2006, Pierluissi 2006). Others have reported that some marsh birds respond as readily to each other's broadcast calls as they do to their own (Glahn 1974, Irish 1974, Kaufmann 1983, Johnson and Dinsmore 1986, Allen et al. 2004). And several past studies have also reported that inclusion of interspecific calls in broadcast sequences either did not affect (Swift et al. 1988) or increased (Todd 1980, Tango et al. 1997, Conway and Nadeau 2006) detection probability of focal marsh birds.

## Objective \#6: Determine optimal timing of surveys across North America. Develop a "zonal" time frame regarding dates to start and end surveys each year in each region.

Probability of vocalization (and hence detection) can change substantially from one month to the next for many species of marsh birds (Conway et al. 1993, Legare et al. 1999, Conway and Gibbs 2001, Bogner and Baldassarre 2002). Providing guidance on optimal timing for marsh bird surveys in each region is an important component of a continental monitoring protocol, especially for marsh birds which are often rare and have low detection probability. Earlier versions of the continental survey protocol provided minimal guidance on survey timing, but optimal timing for surveys likely varies among regions and even among species within a region (Lor and Malecki 2002, Rehm and Baldassarre 2007). We used temperature isoclines based on the average daily maximum temperature for the month of May to develop survey windows for areas across North America (Fig. 14). Recommended survey dates for each isocline were based on the authors' knowledge of breeding phenology for marsh birds at locations within each zone, and feedback from members of the USFWS marsh bird User Acceptance Team (UAT) that were familiar with seasonal breeding and vocalization
patterns for marsh birds in their region. This zonal time frame has been reviewed by biologists throughout North America (including ~ 10 refuge biologists) and changes were made to incorporate their comments. The map (Fig. 14) has been incorporated into the recent version of the North American Marsh Bird Survey Protocols (Conway 2008) and has been posted on the program website (http://www.cals.arizona.edu/ research/azfwru/NationalMarshBird/). We also summarized data for 6 locations in North America that have conducted surveys across a wide range of dates during the spring and summer to examine seasonal trends in numbers detected (Table 6). The peaks identified in Table 6 should be interpreted with caution because they are influenced by a variety of factors: 1) dates that past surveys were conducted at each location (some locations only conducted surveys during a relatively narrow seasonal time frame which may not have included the true peak for some species), 2) migrants and hatch-year birds may create peaks early or late in the season that may obfuscate the seasonal peak in vocalization probability for breeding adults, and 3) peaks identified for some species at some locations are based on only a small number of detections. Indeed, some peaks identified corresponded to the first few weeks that surveys were conducted at that location (Table 6), suggesting that optimal survey timing may be earlier than indicated at those locations. All locations except Grand Bay had peaks for 1 or more species early in the season and peaks for other species later in the season (Table 6). We could only included 6 locations here because most of the locations that conducted marsh bird surveys conducted all surveys during a relatively narrow timeframe (i.e., <9 weeks) that usually did not coincide with the recommended survey window and, not surprisingly, tended to have peaks for some species during their first week of sampling and peaks for other species during their final weeks of sampling. The variation in timing of peaks across locations creates difficulty for recommending optimal survey timing for each region. Based on the patterns presented here, we suggest that multiple surveys should be conducted each year and that the timing of these surveys should be spread out over the course of the spring and summer to help ensure that at least 1 survey is conducted during the peak timing for all target species in each location. Optimal survey windows for each region should probably be based on knowledge of local breeding and migration phenology (if available) because peaks in calling can be influenced by migrants and hatch-year birds. We suggest that optimal survey windows be the focus of further research and adjusted as additional data are available within each region.

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Table 1. Variance components for species of marsh birds used in power analysis based on average number of individuals of each species counted across multiple visits to the same point within a given year.

| Species | NWR | Year | NWR ${ }^{*}$ Year | Error | Total |
| :--- | :---: | :---: | :---: | :---: | :---: |
| American Bittern (AMBI) | 0.0453 | 0.0000 | 0.0200 | 0.1005 | 0.1658 |
| Clapper Rail (CLRA) | 0.2620 | 0.0000 | 0.0082 | 0.1385 | 0.4087 |
| King Rail (KIRA) | 0.0106 | 0.0012 | 0.0000 | 0.0670 | 0.0788 |
| Least Bittern (LEBI) | 0.0411 | 0.0198 | 0.0041 | 0.0774 | 0.1424 |
| Pied-billed Grebe (PBGR) | 0.0702 | 0.0055 | 0.0068 | 0.1316 | 0.2141 |
| Sora (SORA) | 0.1109 | 0.0017 | 0.0151 | 0.1102 | 0.2379 |
| Virginia Rail (VIRA) | 0.0240 | 0.0000 | 0.0049 | 0.0716 | 0.1005 |

Table 2. Variance components for species of marsh birds based on counts from individual visits.

| Species | NWR | Year | NWR $^{*}$ Year | Point | Point ${ }^{*}$ Year | Error | Total |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| American Bittern | 0.0309 | 0.0000 | 0.0187 | 0.0346 | 0.0029 | 0.1147 | 0.2018 |
| Clapper Rail | 0.2037 | 0.0000 | 0.0150 | 0.0663 | 0.0109 | 0.1344 | 0.4303 |
| King Rail | 0.0062 | 0.0007 | 0.0000 | 0.0090 | 0.0075 | 0.0826 | 0.1060 |
| Least Bittern | 0.0308 | 0.0231 | 0.0020 | 0.0203 | 0.0000 | 0.1195 | 0.1957 |
| Pied-billed Grebe | 0.0510 | 0.0041 | 0.0065 | 0.0579 | 0.0073 | 0.1407 | 0.2675 |
| Sora | 0.0887 | 0.0011 | 0.0117 | 0.0267 | 0.0130 | 0.1327 | 0.2739 |
| Virginia Rail | 0.0160 | 0.0001 | 0.0045 | 0.0098 | 0.0090 | 0.0929 | 0.1323 |

Table 3. The number of refuges for which data were available and the relative abundance of each species (average number of birds per survey point; BPS) used for power calculations at the national level.

| Species | Total Refuges | $\operatorname{Ln}(\mathrm{BPS})$ |
| :--- | :---: | :---: |
| American Bittern | 70 | 0.2740 |
| Clapper Rail | 26 | 0.3313 |
| King Rail | 39 | 0.1047 |
| Least Bittern | 63 | 0.2365 |
| Pied-billed Grebe | 68 | 0.2947 |
| Sora | 81 | 0.2405 |
| Virginia Rail | 83 | 0.1510 |

Table 4. The number of refuges for which data were available and the relative abundance of each species (average number of birds per survey point; BPS) used for power calculations at the regional level.

| Species | Min. <br> Refuges | Max. <br> Refuges | Min. <br> $\operatorname{Ln}(\mathrm{BPS})$ | Max. <br> $\operatorname{Ln}(\mathrm{BPS})$ |
| :--- | :---: | :---: | :---: | :---: |
| American Bittern | 5 | 25 | 0.1 | 0.4 |
| Clapper Rail | 2 | 10 | 0.02 | 1.2 |
| King Rail | 2 | 15 | 0.003 | 0.3 |
| Least Bittern | 2 | 20 | 0.008 | 0.8 |
| Pied-billed Grebe | 5 | 25 | 0.09 | 0.9 |
| Sora | 5 | 25 | 0.04 | 0.6 |
| Virginia Rail | 5 | 25 | 0.09 | 0.4 |

Table 5. Relative abundance (mean number of birds detected per survey point) of 13 species of secretive marsh birds at 73 National Wildlife Refuges and Wildlife Management Districts based on surveys using the North American Marsh Bird Monitoring Protocol (Conway 2008). Each unique call-broadcast sequence is assigned a unique Broadcast Sequence Number which identifies the species included in the call-broadcast sequence; many refuges conducted surveys using more than 1 call-broadcast sequence. National and regional averages are included for comparison. The Number of Point-Years indicates the number of survey points that contributed to the means reported for each species. Many locations had breeding AMCO, COMO, or PBGR, but surveyors chose not to record detections for 1 or more of these 3 species, so an empty cell (.) for these species does not necessarily imply that these species were not present at that location.

| Refuge |  |  | Broadcast Sequence: |  |  |  |  |  |  |  |  | $\sum_{\ll}^{\infty}$ | $\begin{aligned} & 0 \\ & \sum_{4}^{0} \\ & \hline \end{aligned}$ | $\begin{aligned} & \stackrel{\rightharpoonup}{2} \\ & \vec{m} \end{aligned}$ | $\begin{aligned} & \overleftrightarrow{\sim} \\ & \breve{3} \end{aligned}$ | $\sum_{0}^{0}$ | $\begin{aligned} & \text { 号 } \end{aligned}$ | $\begin{gathered} \underset{y}{9} \\ \underset{y}{0} \end{gathered}$ | $\sum_{i=1}^{n}$ | $\begin{aligned} & \text { 의 } \\ & 0 \end{aligned}$ | $\begin{aligned} & \text { 《 } \\ & 0 \\ & 0 \end{aligned}$ | $\begin{aligned} & \mathbb{2} \\ & 0 \\ & 0 \end{aligned}$ | $\begin{aligned} & \stackrel{y}{y} \\ & = \end{aligned}$ | $\begin{aligned} & \underset{\sim}{\underset{N}{2}} \\ & \underset{y}{\mid c} \end{aligned}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Spp 1 | Spp 2 | Spp 3 | Spp 4 | Spp 5 | Spp 6 | Spp 7 | Spp 8 | Spp 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| National Average |  |  |  |  |  |  |  |  |  |  |  | . 20 | . 55 | . 03 | . 68 | . 23 | . 11 | . 25 | . 03 | . 47 | . 12 | . 26 | . 21 | . 02 |  |
| FWS Region 1 Average |  |  |  |  |  |  |  |  |  |  |  | . 39 | 1.19 |  |  |  |  |  |  | . 81 |  | . 50 | . 46 |  |  |
| FWS Region 2 Average |  |  |  |  |  |  |  |  |  |  |  | . 08 | 1.40 | . 18 | . 99 | 1.24 | . 11 | 1.08 |  | 1.25 | . 28 | . 61 | . 83 |  |  |
| FWS Region 3 Average |  |  |  |  |  |  |  |  |  |  |  | . 29 | . 70 | . 01 | . 16 | . 01 | . 04 | . 05 |  | . 48 |  | . 44 | . 22 | . 07 |  |
| FWS Region 4 Average |  |  |  |  |  |  |  |  |  |  |  | . 37 | . 11 | . 01 | 1.91 | . 26 | . 17 | . 23 | . 04 | . 08 | . 18 | . 58 | . 05 | . 00 |  |
| FWS Region 5 Average |  |  |  |  |  |  |  |  |  |  |  | . 38 | . 57 | . 00 | 1.09 | . 26 | . 06 | . 05 |  | . 18 |  | . 07 | . 18 | . 00 |  |
| FWS Region 6 Average |  |  |  |  |  |  |  |  |  |  |  | . 17 | . 60 | . 04 |  | . 04 | . 01 | . 02 |  | . 32 |  | . 42 | . 24 | . 01 |  |
| FWS Region 8 Average |  |  |  |  |  |  |  |  |  |  |  | . 84 |  | . 02 | 2.68 | 1.53 |  | . 91 |  | 1.57 |  | . 57 | . 49 |  |  |
| Alberta |  |  |  |  |  |  |  |  |  |  |  | . 01 |  |  |  |  |  |  |  | . 01 |  | . 49 | . 00 |  |  |
| northern Mexico |  |  |  |  |  |  |  |  |  |  |  | . 31 |  | . 05 | 2.54 |  |  | 1.48 |  |  |  | . 44 | . 77 |  |  |
| agassiz nwr | 14 | 3 | LEBI | SORA | VIRA | AMBI | PBGR |  |  |  |  | . 80 | . 02 | . | . | . | . | . 08 | . | . 87 | . | . 98 | . 34 | . | 132 |
| agassiz nwr | 38 | 5 | BLRA | LEBI | YERA | SORA | VIRA | AMBI | PBGR |  |  | . 92 | . 11 | . 00 | . | . | . | . 06 | . | 1.10 | . | 1.51 | . 49 | . 01 | 124 |
| agassiz nwr | 143 | 5 | LEBI | YERA | SORA | VIRA | AMBI | PBGR | RNGR |  |  | . 85 | . | . | . | . | . | . 03 | . | . 70 | . | 1.07 | . 43 | . 02 | 41 |
| bon secour nwr | 45 | 5 | BLRA | LEBI | KIRA | CLRA |  |  |  |  |  | . | . | . 00 | 2.2 |  | . 02 | . 07 | . |  | . |  | . | . | 281 |
| bon secour nwr | 46 | 5 | LEBI | KIRA | CLRA | COMO | PUGA |  |  |  |  | . | . | . | . 14 | . 27 | . 23 | . 22 | . | . | . 57 | . | . | . | 192 |
| alamosa nwr | 5 | 5 | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  |  | . 42 | 1.77 | . | . | . | . |  | . | . 62 | . | . 77 | . 42 | . | 13 |
| alamosa nwr | 17 | 5 | LEBI | SORA | VIRA | AMBI | COMO | AMCO | PBGR |  |  | . 23 | 1.08 | . | . | . 00 | . | . 00 | . | . 36 | . | . 45 | . 05 | . | 14 |
| alamosa nwr | 41 | 5 | BLRA | SORA | VIRA | AMBI | PBGR |  |  |  |  | . 25 | . | . 00 | . | . | . | . | . | . 25 | . | . 61 | . 07 | . | 14 |
| anahuac nwr | 57 | 5 | SESP | BLRA | LEBI | PUGA | COMO | AMCO | CLRA |  |  |  | . 00 | . 00 | . 33 | . 00 | . | . 00 | . |  | . 00 |  | . | . | 6 |
| aransas nwr | 146 | 5 | BLRA | LEBI | SORA | KIRA | CLRA | AMBI | PUGA | LEGR | PBGR | . 00 | . 03 | . 00 | . 08 | . 17 | . 18 | . 12 | . | . 13 | . 37 | . 00 | . |  | 20 |
| assabet river nwr | 11 | 5 | BLRA | LEBI | SORA | VIRA | KIRA |  |  |  |  | . | . | . 00 | . | . | . 00 | . 00 | . | . | . | . 00 | . 18 | . | 13 |
| assabet river nwr | 34 | 5 | LEBI | SORA | VIRA | KIRA | AMBI | COMO | PBGR |  |  | . 01 |  |  |  | . 00 | . 00 | . 06 | . | . 00 |  | . 00 | . 14 |  | 14 |
| back bay nwr | 11 | 5 | BLRA | LEBI | SORA | VIRA | KIRA |  |  |  |  |  | . 02 | . 00 |  |  | . 25 | . 20 |  |  |  | . 06 | . 01 | . | 182 |
| bald knob nwr | 50 | 5 | BLRA | LEBI | YERA | SORA | VIRA | KIRA | AMBI | COMO | PBGR | . 00 | . | . 00 | . | . 00 | . 00 | . 00 | . | . 00 | . | . 00 | . 00 | . 00 | 13 |
| bayou sauvage nwr | 37 | 5 | KIRA | CLRA | COMO | PUGA |  |  |  |  |  | . | . | . | . 61 | . 49 | . 41 | . | . | . | . 00 | . | . | . | 17 |
| bear lake | 5 | 5 | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  |  | 1.73 | 1.36 | . | . | . | . | . | . | . 94 | . | . 11 | . 66 | . | 50 |
| bear lake | 131 | 5 | SORA | VIRA | AMBI | PBGR | WISN |  |  |  |  | 1.36 | . 48 | . | . | . | . | . | . | . 75 | . | . 22 | . 55 | . | 66 |


| big branch marsh nwr | 37 | 5 | KIRA | CLRA | COMO | PUGA |  |  |  |  |  | . | . | . | . 52 | . 11 | . 30 | . |  | . | . 02 | . |  |  | 18 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| bill williams nwr | 504 | 3 | BLRA | BLRA | BLRA |  |  |  |  |  |  |  |  | . 41 | . | . | . |  |  |  | . |  | . 13 | . | 64 |
| bitter lake nwr | 14 | 3 | LEBI | SORA | VIRA | AMBI | PBGR |  |  |  |  | . 00 | . | . | . | . | . | . 00 |  | . 03 | . | . 02 | 1.2 | . | 60 |
| bosque del apache nwr | 43 | 5 | LEBI | SORA | VIRA | AMBI | COMO | PBGR |  |  |  | . 01 | 3.03 | . | . | . 07 | . | . 11 |  | 1.58 | . | . 01 | . 40 |  | 72 |
| bowdoin nwr | 77 | 5 | YERA | SORA | VIRA | AMBI | PBGR |  |  |  |  | . 00 | . 31 | . | . | . | . | . |  | . 13 |  | 1.06 | . 00 | . 00 | 16 |
| camas nwr | 5 | 5 | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  |  | . 00 | 2.43 |  |  |  |  |  |  | . 18 |  | . 75 | . 68 |  | 8 |
| camas nwr | 131 | 5 | SORA | VIRA | AMBI | PBGR | WISN |  |  |  |  | . 14 | . 85 | . | . | . | . | . |  | . 40 |  | . 88 | . 69 |  | 16 |
| cedar island nwr | 9 | 5 | BLRA | CLRA |  |  |  |  |  |  |  |  | . | . 02 | 2.1 | . | . | . |  | . | . | . | . 02 | . | 19 |
| cibola nwr | 504 | 3 | BLRA | BLRA | BLRA |  |  |  |  |  |  |  | . | . 00 | . 20 | . | . | . 89 |  | . | . | . | . |  | 44 |
| clarence cannon nwr | 59 | 5 | LEBI | SORA | VIRA |  |  |  |  |  |  | . 02 | . | . 04 | . | . | . 09 | . 34 |  | . | . | . 02 | . 03 | . 03 | 23 |
| clarence cannon nwr | 119 | 5 | BLRA | LEBI | YERA | SORA | VIRA | KIRA | AMBI |  |  | . 10 | . | . 00 | . |  | . 05 | . 09 |  | . | . | . 27 | . 05 | . 00 | 60 |
| clarence cannon nwr | 120 | 5 | BLRA | LEBI | YERA | SORA | VIRA | CLRA | AMBI | COMO | PBGR | . 00 | . | . 00 | . 00 | . 00 | . | . 00 |  | . 98 |  | . 02 | . 00 | . 00 | 29 |
| columbia nwr | 42 | 5 | SORA | VIRA | AMBI | PBGR |  |  |  |  |  | . 39 | . 01 | . | . |  | . |  |  | . 71 |  | . 03 | . 56 |  | 63 |
| crane meadows nwr | 26 | 5 | LEBI | YERA | SORA | VIRA | AMBI | COMO | PBGR |  |  | . 17 | . 01 | . | . | . 01 | . | . 01 |  | . 04 | . | . 07 | . 03 | . 00 | 91 |
| great river nwr | 59 | 5 | LEBI | SORA | VIRA |  |  |  |  |  |  |  | . | . | . | . |  | . 00 |  | . | . | . 13 | . 00 |  | 4 |
| great river nwr | 119 | 5 | BLRA | LEBI | YERA | SORA | VIRA | KIRA | AMBI |  |  | . 00 | . | . 00 |  |  | . 00 | . 00 |  |  | . | . 43 | . 00 | . 05 | 6 |
| great river nwr | 120 | 5 | BLRA | LEBI | YERA | SORA | VIRA | CLRA | AMBI | COMO | PBGR | . 00 | . | . 00 | . 00 | . 00 | . | . 00 |  | . 00 | . | . 50 | . 00 | . 00 | 6 |
| driftless area nwr | 58 | 5 | VIRA | SORA | AMBI | LEBI |  |  |  |  |  | . 03 | . | . | . | . | . | . 04 |  | . | . | . 06 | . 17 | . | 28 |
| eastern shore of Virginia nwr | 9 | 5 | BLRA | CLRA |  |  |  |  |  |  |  |  | . | . 00 | 3.7 | . | . 01 |  |  | . | . |  |  | . | 61 |
| eastern shore of virginia nwr | 11 | 5 | BLRA | LEBI | SORA | VIRA | KIRA |  |  |  |  | . | . | . 00 | 1.4 | . | . 29 | . 00 |  | . | . | . 00 | . 00 | . | 8 |
| eastern shore of virginia nwr | 66 | 5 | BLRA | VIRA | KIRA | CLRA |  |  |  |  |  | . | . | . 00 | 4.7 | . | . 00 | . |  | . | . |  | . 00 | . | 32 |
| edwin b. forsythe nwr | 125 | 5 | CLRA | BLRA |  |  |  |  |  |  |  |  | . | . 00 | . 32 |  |  |  |  |  | . |  |  |  | 36 |
| great bay nwr | 30 | 5 | LEBI | SORA | VIRA | YERA | COMO | PBGR |  |  |  |  | . | . | . | . 02 | . 01 | . 03 |  | . 03 | . | . 02 | . 15 | . 00 | 39 |
| great meadows nwr | 11 | 5 | BLRA | LEBI | SORA | VIRA | KIRA |  |  |  |  | . 02 | . | . 00 | . |  | . 00 | . 02 |  | . | . | . 02 | . 16 |  | 16 |
| great meadows nwr | 34 | 5 | LEBI | SORA | VIRA | KIRA | AMBI | COMO | PBGR |  |  | . 00 | . 01 | . | . | . 00 | . 00 | . 00 |  | . 04 | . | . 10 | . 27 |  | 41 |
| great swamp nwr | 30 | 5 | LEBI | SORA | VIRA | YERA | COMO | PBGR |  |  |  | . | . | . | . | . 00 | . | . 04 |  | . 00 |  | . 08 | . 43 | . 00 | 17 |
| hamden slough nwr | 50 | 5 | BLRA | LEBI | YERA | SORA | VIRA | KIRA | AMBI | COMO | PBGR | . 25 | . 93 | . 00 | . | . 00 | . 00 | . 04 |  | 1.04 | . | . 45 | . 69 | . 00 | 19 |
| havasu nwr | 121 | 5 | BLRA | LEBI | VIRA | CLRA |  |  |  |  |  |  | . 63 | . 00 | . 08 | . 70 | . | 1.17 |  | . 90 | . |  | . 23 |  | 95 |
| havasu nwr | 138 | 5 | BLRA | LEBI | CLRA |  |  |  |  |  |  |  |  | . 00 | . 60 | . | . | . 62 |  | . 68 | . |  | . 11 |  | 53 |
| havasu nwr | 153 | 5 | CLRA | BLRA | LEBI | VIRA |  |  |  |  |  |  | . 09 | . 00 | . 25 | 1.10 | . | 1.23 |  | 1.01 | . | . 03 | . 28 |  | 460 |
| havasu nwr | 504 | 3 | BLRA | BLRA | BLRA |  |  |  |  |  |  | . | . 01 | . 00 | . 31 |  | . | . 10 |  | . 03 | . | . 02 | . 22 |  | 123 |
| havasu nwr | 508 | 6 |  |  |  |  |  |  |  |  |  | . | . 59 | . | . | . | . | . 32 |  | . 36 | . |  | . | . | 22 |
| havasu nwr | 509 | 8 |  |  |  |  |  |  |  |  |  | . | 1.24 | . | . 03 | . 09 | . | . 94 |  | . 88 | . | . | . 12 | . | 95 |
| horicon nwr | 25 | 5 | LEBI | SORA | VIRA | KIRA | AMBI |  |  |  |  | . 11 | . | . | . | . | . 01 | . 05 |  |  | . | 1.92 | . 45 |  | 67 |
| horicon nwr | 47 | 5 | LEBI | YERA | SORA | VIRA | KIRA | AMBI |  |  |  | . 21 | . | . | . |  | . 07 | . 04 | . | . | . | 2.32 | . 75 | . 00 | 14 |
| illinois river nwfr | 20 | 5 | BLRA | LEBI | SORA | VIRA | KIRA | AMBI | COMO | AMCO |  | . 00 | . 78 | . 00 | . | . 00 | . 00 | . 10 |  | . 05 | . | . 14 | . 24 |  | 30 |
| imperial nwr | 32 | 5 | BLRA | LEBI | VIRA | CLRA | AMBI |  |  |  |  | . 00 | . 37 | . 06 | . 30 | . 02 | . | 1.41 | . | . 23 | . | . 03 | . 07 | . | 54 |
| imperial nwr | 116 | 5 | BLRA | LEBI | SORA | VIRA | CLRA |  |  |  |  | . | . | . 10 | . 34 | . 39 | . | 1.25 |  | 1.56 | . | . 05 | . 05 | . | 56 |
| imperial nwr | 121 | 5 | BLRA | LEBI | VIRA | CLRA |  |  |  |  |  | . | . 20 | . 07 | . 25 | . 47 | . | 1.35 |  | 1.48 | . | . 05 | . 01 | . | 214 |
| imperial nwr | 153 | 5 | CLRA | BLRA | LEBI | VIRA |  |  |  |  |  | . | . 36 | . 01 | . 04 | . 42 | . | 1.25 |  | 1.21 | . | . 02 | . 01 | . | 153 |
| imperial nwr | 500 | 3 | BLRA | LEBI | SORA | VIRA | CLRA | PBGR |  |  |  |  | . 19 | . 00 | . 01 | . 36 | . | 1.10 | . | 1.20 | . | . 00 | . 00 |  | 57 |
| imperial nwr | 501 | 3 | BLRA | LEBI | VIRA | SORA | CLRA | PBGR |  |  |  | . | . | . 15 | . 31 | . | . | 1.54 | . | . 00 | . | . 00 | . 23 | . | 13 |
| imperial nwr | 502 | 3 | BLRA | BLRA | BLRA | CLRA | CLRA | CLRA |  |  |  | . | . | . 04 | . 00 |  | . | . 96 |  |  | . | . | . 08 |  | 13 |
| imperial nwr | 503 | 3 | CLRA | CLRA | CLRA | CLRA | CLRA | CLRA |  |  |  | . | . |  | . 15 |  | . | 1.38 | . |  | . |  | . 15 |  | 13 |
| imperial nwr | 504 | 3 | BLRA | BLRA | BLRA |  |  |  |  |  |  | . 01 | . 19 | . 10 | . 30 | . 20 | . | . 69 | . | . 74 | . | . 11 | . 02 | . | 825 |
| imperial nwr | 505 | 3 | BLRA | SORA | VIRA | CLRA |  |  |  |  |  | . 03 | . | . 64 | . 24 | . 61 | . | . 89 | . | . 78 | . | . 62 | . 76 | . | 37 |
| imperial nwr | 508 | 6 |  |  |  |  |  |  |  |  |  | . 01 | 1.48 | . 03 | . 14 | . 04 | . | . 57 | . | . 65 | . | . 01 | . | . | 82 |
| imperial nwr | 509 | 8 |  |  |  |  |  |  |  |  |  |  | 1.31 | . | . 26 | . 02 | . | 1.57 | . | . 73 | . |  |  |  | 43 |


| iroquois nwr | 10 | 5 | LEBI | YERA | SORA | VIRA | COMO | PBGR |  |  |  | . 08 | . 66 | . | . | . 58 | . | . 05 |  | . 86 |  | . 16 | . 28 | . 00 | 107 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| iroquois nwr | 30 | 5 | LEBI | SORA | VIRA | YERA | COMO | PBGR |  |  |  | . 17 | . 38 | . |  | . 10 |  | . 01 |  | . 40 |  | . 14 | . 28 | . 00 | 72 |
| j.n. ding darling nwr | 27 | 5 | LEBI | SORA | VIRA | KIRA | CLRA | AMBI | COMO | AMCO |  | . 00 | . 09 | . | . 09 | . 86 | . 04 | . 01 |  |  |  | . 15 | . 00 |  | 37 |
| lacreek nwr | 141 | 5 | SORA | VIRA | AMBI |  |  |  |  |  |  | . 28 | . | . | . | . | . | . |  | . 01 |  | . 15 | . 28 |  | 162 |
| laguna cartagena nwr | 4 | 5 | YERA | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  | . 00 | . 00 | . 02 | . | . 71 | . |  |  | . 32 |  | . 30 | . 00 | . 00 | 32 |
| lake alice nwr | 77 | 5 | YERA | SORA | VIRA | AMBI | PBGR |  |  |  |  | . 14 | . 76 | . | . |  | . | . 03 |  | 1.25 |  | . 33 | . 24 | . 00 | 21 |
| lake umbagog nwr | 30 | 5 | LEBI | SORA | VIRA | YERA | COMO | PBGR |  |  |  | . 10 | . |  | . | . 00 |  | . 00 |  | . 00 |  | . 02 | . 22 | . 00 | 96 |
| litchfield wmd | 2 | 5 | BLRA | LEBI | SORA | VIRA | KIRA | AMBI | COMO | PBGR |  | . 04 | . | . 00 | . | . 00 | . 00 | . 05 |  | . 69 |  | . 46 | . 30 |  | 93 |
| loxahatchee nwr | 23 | 5 | LEBI | KIRA |  |  |  |  |  |  |  | . 03 | . |  | . | . 47 | . 23 | . 20 |  | . 03 |  |  |  | . 03 | 15 |
| mackay island nwr | 15 | 5 | BLRA | LEBI | VIRA | KIRA | CLRA | COMO |  |  |  | . 19 |  | . 01 | . 01 | . 12 | 1.43 | . 70 |  | . 16 |  |  | . 17 |  | 52 |
| mackay island nwr | 120 | 5 | BLRA | LEBI | YERA | SORA | VIRA | CLRA | AMBI | COMO | PBGR | . 04 | . | . 00 | . 13 | . 00 | . 75 | . 29 |  | . 19 |  | . 19 | . 27 | . 00 | 12 |
| martin nwr | 80 | 5 | BLRA | LEBI | SORA | VIRA | KIRA | CLRA |  |  |  | . | . | . 00 | 2.5 | . | . 00 | . 00 |  | . |  | . 00 | . 04 |  | 18 |
| mattamuskeet nwr | 11 | 5 | BLRA | LEBI | SORA | VIRA | KIRA |  |  |  |  | . 01 | . | . 00 | . | . | . 51 | . 29 |  |  |  | . 25 | . 08 |  | 18 |
| medecine lake nwr | 4 | 5 | YERA | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  | . 54 | . 68 |  | . | . | . | . |  | 1.89 |  | 1.32 | . 33 | . 00 | 29 |
| merrit island nwr | 6 | 5 | BLRA | LEBI | KIRA | COMO | PBGR |  |  |  |  | . | . | . 00 | . | 1.00 | . 00 | . 07 |  | . 00 |  | . |  |  | 10 |
| merrit island nwr | 64 | 5 | BLRA | LEBI | KIRA |  |  |  |  |  |  |  | . 03 | . 00 |  | 1.13 | . 00 | . 07 |  |  |  |  |  |  | 10 |
| minnesota valley nwr | 34 | 5 | LEBI | SORA | VIRA | KIRA | AMBI | COMO | PBGR |  |  | . 00 | . | . | . | . 00 | . 00 | . 01 | . | . 02 |  | . 13 | . 49 | . | 24 |
| missiquoi nwr | 30 | 5 | LEBI | SORA | VIRA | YERA | COMO | PBGR |  |  |  | . 14 | . |  | . | . 55 | . | . 02 |  | 1.05 |  | . 26 | . 31 | . 00 | 21 |
| missiquoi nwr | 52 | 5 | VIRA | SORA | LEBI | COMO | PBGR |  |  |  |  | . 20 |  |  |  | . 43 |  | . 00 |  | . 80 |  | . 00 | . 00 |  | 20 |
| mississippi sandhill crane nwr | 65 | 5 | BLRA | KIRA |  |  |  |  |  |  |  | . | . 02 | . 00 | . 08 | . | . 02 | . | . | . |  | . | . | . | 24 |
| monte vista nwr | 5 | 5 | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  |  | . 29 | . 14 | . | . | . | . | . |  | . 07 |  | . 46 | . 21 |  | 14 |
| monte vista nwr | 17 | 5 | LEBI | SORA | VIRA | AMBI | COMO | AMCO | PBGR |  |  | . 22 | . 33 | . |  | . 00 | . | . 00 | . | . 20 |  | . 70 | . 06 |  | 21 |
| monte vista nwr | 41 | 5 | BLRA | SORA | VIRA | AMBI | PBGR |  |  |  |  | . 75 | . | . 00 | . |  | . | . | . | . 13 |  | . 52 | . 00 | . | 16 |
| moosehorn nwr | 10 | 5 | LEBI | YERA | SORA | VIRA | COMO | PBGR |  |  |  | . 07 | . |  |  | . 00 |  | . 00 | . | . 02 |  | . 11 | . 11 | . 00 | 103 |
| moosehorn nwr | 30 | 5 | LEBI | SORA | VIRA | YERA | COMO | PBGR |  |  |  | . 03 | . | . |  | . 00 | . | . 00 | . | . 02 |  | . 11 | . 13 | . 00 | 573 |
| morris wmd | 50 | 5 | BLRA | LEBI | YERA | SORA | VIRA | KIRA | AMBI | COMO | PBGR | . 22 |  | . 00 | . | . 00 | . 00 | . 01 | . | . 72 |  | . 24 | . 09 | . 00 | 120 |
| mud lake wma | 5 | 5 | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  |  | . 29 | 2.29 | . | . |  |  |  |  | 2.02 |  | . 14 | . 44 |  | 14 |
| mud lake wma | 131 | 5 | SORA | VIRA | AMBI | PBGR | WISN |  |  |  |  | . 06 | . 59 | . | . | . | . | . | . | 2.36 |  | . 20 | . 09 | . | 11 |
| national elk refuge | 4 | 5 | YERA | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  | . 00 | . 01 | . | . |  |  | . | . | . 00 |  | . 41 | . 00 | . 00 | 34 |
| national elk refuge | 77 | 5 | YERA | SORA | VIRA | AMBI | PBGR |  |  |  |  | . 00 | . | . | . | . | . | . | . | . 00 |  | . 00 | . 00 | . 00 | 16 |
| nisqually nwr complex | 5 | 5 | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  |  | . 78 | . 11 | . | . | . | . | . | . | . 00 |  | . 22 | . 78 |  | 9 |
| nisqually nwr complex | 40 | 5 | SORA | VIRA | AMBI | AMCO | PBGR | GBHE | WISN |  |  | . 10 | . 00 | . | . | . | . | . | . | . 05 |  | . 01 | . 19 | . | 18 |
| nomans land island nwr | 34 | 5 | LEBI | SORA | VIRA | KIRA | AMBI | COMO | PBGR |  |  | . 00 | . | . | . | . 00 | . 00 | . 00 | . | . 00 |  | . 00 | . 47 | . | 36 |
| ouray nwr | 5 | 5 | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  |  | . 19 | . 24 | . | . | . | . | . | . | . 64 |  | . 01 | . 07 | . | 25 |
| ouray nwr | 17 | 5 | LEBI | SORA | VIRA | AMBI | COMO | AMCO | PBGR |  |  | . 51 | . 96 | . | . | . 00 | . | . 00 | . | . 85 |  | . 04 | . 01 | . | 26 |
| ouray nwr | 63 | 5 | LEBI | SORA | VIRA | AMBI |  |  |  |  |  | . 50 | . | . | . | . | . | . 01 | . | . |  | . 11 | . 11 | . | 62 |
| oxbow nwr | 11 | 5 | BLRA | LEBI | SORA | VIRA | KIRA |  |  |  |  | . | . | . 00 | . |  | . 00 | . 00 | . | . | . | . 00 | . 20 | . | 8 |
| oxbow nwr | 34 | 5 | LEBI | SORA | VIRA | KIRA | AMBI | COMO | PBGR |  |  | . 00 | . |  |  | . 00 | . 00 | . 00 | . | . 02 |  | . 03 | . 05 | . | 19 |
| quivira nwr | 39 | 5 | BLRA | LEBI | SORA | VIRA | KIRA | AMBI | COMO |  |  | . 25 |  | . 00 | . | . 00 | . 00 | . 00 | . |  |  | . 03 | . 27 |  | 30 |
| rice lake nwr | 22 | 5 | LEBI | YERA | SORA | VIRA | AMBI | PBGR |  |  |  | . 83 | . | . | . | . | . | . 02 | . | . 18 |  | . 34 | . 17 | . 52 | 62 |
| san bernardino/leslie canyon nwr | 17 | 5 | LEBI | SORA | VIRA | AMBI | COMO | AMCO | PBGR |  |  | . 00 | . 57 | . | . | . 00 | . | . 00 | . | . 00 | . | . 10 | . 00 | . | 7 |
| seney nwr | 14 | 3 | LEBI | SORA | VIRA | AMBI | PBGR |  |  |  |  | . 54 | . | . | . | . | . | . 00 | . | . 09 |  | . 78 | . 09 | . | 18 |
| sequoyah nwr | 85 | 5 | LEBI | VIRA | KIRA | AMBI | COMO | AMCO | PBGR |  |  | . 02 | . 10 |  |  | . 04 | . 00 | . 00 | . | . 21 |  | . 27 | . 15 |  | 14 |
| sequoyah nwr | 129 | 5 | SORA | VIRA | AMBI | COMO | AMCO | PBGR |  |  |  | . 02 | . 02 | . | . | . 00 | . |  | . | . 45 |  | . 25 | . 07 | . | 14 |
| silvio o. conte nfwr | 28 | 5 | LEBI | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  | . 00 | . 00 | . | . | . | . | . 00 | . | . 00 |  | . 00 | . 00 | . | 3 |
| sonny bonno-salton sea nwr | 116 | 5 | BLRA | LEBI | SORA | VIRA | CLRA |  |  |  |  | . 04 | . | . 00 | 3.0 | . 91 | . | . 34 | . | . 53 |  | . 26 | . 04 | . | 175 |
| sonny bonno-salton sea nwr | 504 | 3 | BLRA | BLRA | BLRA |  |  |  |  |  |  | . 02 | . | . 01 | . 83 | . 18 | . | . 14 | . | . 05 | . | . 01 | . 02 | . | 403 |


| st johns nwr | 6 | 5 | BLRA | LEBI | KIRA | COMO | PBGR |  |  |  |  | . |  | . 06 | . 02 | . 04 | . 08 | . 00 | . | . 00 | . |  | . |  | 28 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| st johns nwr | 64 | 5 | BLRA | LEBI | KIRA |  |  |  |  |  |  |  |  | . 00 |  |  | . 03 | . 00 |  |  |  |  | . |  | 11 |
| st vincent nwr | 8 | 5 | BLRA | LEBI | KIRA | CLRA | AMBI | COMO | PUGA | AMCO | PBGR | . 00 | . 00 | . 00 | . 36 | . 14 | . 00 | . 07 |  | . 00 | . 00 |  |  |  | 14 |
| st vincent nwr | 140 | 5 | BLRA | LEBI | CLRA | COMO | PUGA |  |  |  |  | . | . 01 | . 00 | 1.3 | . 35 | . 01 | . 47 | . |  | . 02 | . 01 | . |  | 84 |
| stewart b mckinney nwr | 9 | 5 | BLRA | CLRA |  |  |  |  |  |  |  |  |  | . 00 | 1.3 |  |  |  | . |  |  |  |  |  | 12 |
| stewart b mckinney nwr | 11 | 5 | BLRA | LEBI | SORA | VIRA | KIRA |  |  |  |  |  |  | . 00 | . 14 |  | . 00 | . 00 |  |  |  | . 00 | 86 |  | 7 |
| stewart b mckinney nwr | 51 | 5 | BLRA | LEBI | SORA | VIRA | KIRA | CLRA | PBGR |  |  |  |  | . 00 | . 83 |  | . 03 | . 04 |  | . 00 |  | . 00 | . 19 |  | 31 |
| stewart b mckinney nwr | 80 | 5 | BLRA | LEBI | SORA | VIRA | KIRA | CLRA |  |  |  |  |  | . 00 | . 00 |  | . 00 | . 00 |  |  |  | . 00 | . 00 |  | 2 |
| stewart b mckinney nwr | 124 | 5 | BLRA | LEBI | SORA | VIRA | KIRA | PBGR |  |  |  |  |  | . 00 | 1.5 |  | . 00 | . 25 |  | . 00 |  | . 00 | . 00 |  | 2 |
| supawna meadows nwr | 11 | 5 | BLRA | LEBI | SORA | VIRA | KIRA |  |  |  |  |  | . | . 00 | 1.3 |  | . 00 | . 00 | . |  |  | . 07 | . 07 |  | 28 |
| supawna meadows nwr | 44 | 5 | LEBI | SORA | VIRA | KIRA | CLRA |  |  |  |  |  | . |  | . 57 |  | . 15 | . 17 |  |  |  | . 01 | . 02 |  | 75 |
| ten thousand islands nwr | 21 | 5 | LEBI | KIRA | CLRA | PUGA | PBGR | LIMP |  |  |  |  |  |  | . 13 | . 77 | . 52 | . 03 | . 03 | . 13 | . 00 |  |  |  | 53 |
| tishomingo nwr | 59 | 5 | LEBI | SORA | VIRA |  |  |  |  |  |  | . | . 10 |  |  |  |  | . 00 |  |  |  | . 00 | . 00 | . | 5 |
| tishomingo nwr | 116 | 5 | BLRA | LEBI | SORA | VIRA | CLRA |  |  |  |  |  |  | . 00 | . 00 |  |  | . 00 |  |  |  | . 00 | . 00 |  | 5 |
| turnbull nwr | 5 | 5 | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  |  | . 08 | 2.61 | . | . | . | . |  | . | . 88 | . | . 39 | . 45 |  | 120 |
| upper mississippi river nw\&fr | 28 | 5 | LEBI | SORA | VIRA | AMBI | AMCO | PBGR |  |  |  | . 00 | . 00 |  |  |  | . | . 06 |  | . 07 |  | . 13 | . 50 |  | 47 |

Table 6. Weeks within the calendar year (i.e., week $10=5-11$ Mar; week $15=9-15$ Apr; week $20=14-20$ May; week $25=$ 18-24 Jun) when numbers of birds detected per point were highest for each of 10 species of marsh birds at each of 6 locations. We only included locations that conducted surveys throughout (and beyond) the currently recommended survey windows (Fig. 11) and that had sufficient numbers of detections that allowed identification of seasonal peaks in detections. If 2 peaks were observed, we chose the most sustained peal. Peaks that were most distinct are in bold and peaks that fall outside of currently recommended survey windows are in red. Although most of the species are thought to have lower rates of vocalization during migration, many of these peaks may be caused by an influx of migrant individuals during that time period. Most of the locations not included here started surveys later than the currently recommended survey windows, preventing evaluation of optimal timing.

|  | Weeks surveys were conducted | COMO | LEBI | AMBI | BLRA | CLRA | KIRA | SORA | VIRA | YERA | PBGR | All spp | Currently recomm. survey window |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Imperial NWR, s. AZ \& CA | 10-31 | 13-15 | 24-27 | 10-15 ${ }^{1}$ | 13-18 | 15-18 |  | 13-15 | 10-18 |  | 13-16 | 10-27 ${ }^{1}$ | 11.5-17 |
| Imperial Reservoir, s. AZ \& CA | 10-30 | 13-16 | 26-27 |  | not obv | 13-15 |  | 13-15 | 10-11 ${ }^{1}$ |  | 10-14 ${ }^{1}$ | $10-27^{1}$ | 11.5-17 |
| Grand Bay area, se. MS | 11-29 | 23-26 | 24-27 |  |  | not obv | 23-25 |  |  |  |  | 23-27 | 14-19 |
| Clarence Cannon NWR, MO | 14-28 |  | 21-23 | 18-20 |  |  | 22-23 | 17-18 | 16-17 | not obv |  | 16-23 | 16-21.5 |
| Agassiz NWR, MN | 19-26 |  | 24-25 | 22-23 |  |  |  | $19-21^{1}$ | 19-21 ${ }^{1}$ | 19-21 ${ }^{1}$ | 23-25 | 19-25 ${ }^{1}$ | 18-24 |
| Prairie Potholes, MN | 17-29 |  | 26-27 | 20-22 |  |  |  | 20-21 | 21-22 | 19-21 | 17-18 ${ }^{1}$ | 17-27 ${ }^{1}$ | 18-26 |

${ }^{1}$ Peak number detected per point corresponded with the first weeks that surveys were conducted (and hence, may be even earlier).

Figure 1. The proportion of American Bitterns detected during each 1-min segment of marsh bird surveys based on: a) all locations throughout North America ( $n=3216$ detections), b) locations throughout FWS Region 1 (includes the new Region 8), c) locations throughout FWS Region 3, d) locations throughout FWS Region 6. For each of the 4 panels, we only included 1-min segments that had little or no missing data (i.e., we only included data for the 1-min LEBI and YERa broadcast segment in the panel for Region 3 because these species were not commonly included in the broadcast sequence in the other regions). The conspecific broadcast segment is highlighted in red.

Figure 2. The proportion of American Bitterns detected during each 1-min segment of marsh bird surveys from 4 locations in North American that had the most bitterns detected: Agassiz NWR, Bear Lake NWR, Red Lake Chippewa Lands, and the Prairie Pothole region. The conspecific broadcast segment is highlighted in red.

Figure 3. The proportion of American Bitterns detected during each 1-min segment of marsh bird surveys throughout North America based on the 938 birds that were detected $\leq 100 \mathrm{~m}$ from the surveyor. The conspecific broadcast segment is highlighted in red.

Figure 4. The percentage of Least Bitterns that were detected during 1-min survey segments: 1-min passive segments, 1 min during which Least Bittern calls were being broadcast, and the 41 -min segments of call-broadcast that immediately followed the 1-min of conspecific calls. We examined 2 different subsets of the available data: a) surveys that had $\geq 3$ 1min passive segments ( $n=2403$ Least Bittern detections), and b) surveys that had 51 -min passive segments ( $n=\overline{8} 47$ Least Bittern detections). The 4 species whose calls followed the Least Bittern calls varied among the 14 locations included in these analyses. The conspecific broadcast segment is highlighted in red.

Figure 5. The percentage of American Bitterns that were detected during the 7 -min call-broadcast segment was higher than the percentage detected during the initial 5-min passive segment, and the difference was greatest when bittern calls were last in the broadcast sequence. The number of bitterns detected upon which the percentages were based (and the survey locations) from left to right: 56 (Alamosa NWR, Monte Vista NWR, Ouray NWR), 144 (Crane Meadows NWR, Agassiz NWR), 596 (Agassiz NWR, Red Lake Band of the Chippewa Lands), 74 (Clarence Cannon NWR). Surveyors at Agassiz NWR used 2 separate broadcast sequences.

Figure 6. The percentage of Clapper Rails that were detected during the 4-min call-broadcast segment was higher than the percentage detected during the initial 5-min passive segment, and the increase in detection probability as a result of call-broadcast was similar regardless of whether the Clapper Rail calls were first in the broadcast sequence or last in the
broadcast sequence. The percentages were based was 321 and 330 Clapper Rails detected for the 2 types of broadcast sequences.

Figure 7. The proportion of birds detected during each 1-min segment of marsh bird surveys throughout North America for Black Rails, Least Bitterns, and Yellow Rails. Sample sizes for the 13 bars on the right side of each panel are: BLRA ( $180,162,0,0,177,0,162,0,0,0,0,0,0$ ); LEBI ( $5512,5726,171,1124,5280,638,5320,709,662,433,215,423,0$ ); YERa ( $0,121,121,121,121,0,0,121,0,0,0,116,0$ ). The conspecific broadcast segment is highlighted in red. Proportions that differed from the average proportion detected during a 1-min passive segment are indicated by * $P<$ $0.01)$ or ** $(P<0.001)$.

Figure 8. The proportion of birds detected during each 1-min segment of marsh bird surveys throughout North America for Soras, Virginia Rails, and King Rails. Sample sizes for the 13 bars on the right side of each panel are: SORA (2224, 3221, 2358, 5734, 5734, 1483, 258, 5337, 594, 0, 1033, 4964, 1038); VIRA (1813, 2728, 992, 3938, 4737, 850, 963, $3764,783,0,856,3517,1017)$; KIRA (440, 619, $0,234,476,656,415,85,386,211,0,0,0)$. The conspecific broadcast segment is highlighted in red. Proportions that differed from the average proportion detected during a 1-min passive segment are indicated by * $(P<0.01)$ or ** $(P<0.001)$.

Figure 9. The proportion of birds detected during each 1-min segment of marsh bird surveys throughout North America for Clapper Rails, American Bitterns, and Common Moorhens. Sample sizes for the 13 bars that on the right side of each panel are: CLRA $(6690,5889,0,2404,3609,2791,6843,591,1894,1856,1378,1431,0)$; AMBI ( $980,1583,1206,3177$, $3179,348,0,3179,225,0,608,2885,886)$; COMO (326, 665, 0, 317, 377, 342, 522, 254, 694, 335, 240, 252, 0). The conspecific broadcast segment is highlighted in red. Proportions that differed from the average proportion detected during a 1-min passive segment are indicated by * $(P<0.01)$ or ** $(P<0.001)$.

Figure 10. The proportion of birds detected during each 1-min segment of marsh bird surveys throughout North America for Purple Gallinules, American Coots, Pied-billed Grebes, and Wilson's Snipe. Sample sizes for the 13 bars that on the right side of each panel are: PUGA ( $0,201,0,0,0,193,186,0,159,202,0,0,0)$; AMCO (94, 211, 0, 2013, 2021, 0, 0, 2021, 212, 0, 2021, 1972, 0); PBGR (1597, 2682, 1760, 6470, 6584, 956, 168, 6306, 1475, 131, 1587, 6607, 2327); WISN $(0,0,0,918,918,0,0,918,0,0,0,918,918)$. The conspecific broadcast segment is highlighted in red. Proportions that differed from the average proportion detected during a 1-min passive segment are indicated by * $(P<0.01)$ or ** $(P<$ 0.001 ).

Figure 11. The percentage of Least Bitterns that were detected during 1-min survey segments for the 4 call-broadcast sequences with the most Least Bittern detections. The conspecific broadcast segment is highlighted in red.

Figure 12. The percentage of King Rails that were detected during 1-min survey segments for the 5 call-broadcast sequences with the most King Rail detections. The conspecific broadcast segment is highlighted in red.

Figure 13. The percentage of Clapper Rails that were detected during 1-min survey segments for the 4 call-broadcast sequences with the most Clapper Rail detections. The conspecific broadcast segment is highlighted in red.

Figure 14. Suggested survey windows for conducting marsh bird surveys across North America based on average daily maximum temperatures during the month of May (from 1971-2000 in the U.S. and 1961-1990 in Canada). The U.S. temperature data is from Oregon State University (http://prism.oregonstate.edu/products/matrix.phtml?vartype=tmin\&view=maps) and the Canadian temperature data is from Environment Canada (http://sis.agr.gc.ca/cansis/nsdb/ecostrat/district/climat.html).

Appendix 1. The effects of 4 variables on the power to detection population trends for 7 species of marsh birds: frequency of sampling (annual or biannual surveys), number of years sampled, number of points sampled each year, and the \% annual decline one wishes to detect ( $1 \%, 3 \%$, or $5 \%$ ). Analyses are based on available data for each species across their range in North America. The 7 species for which we conducted power analyses were: LEBI, VIRA, SORA, KIRA, CLRA, AMBI, and PBGR.

Appendix 2. The effects of 4 variables on the power to detection population trends for 7 species of marsh birds: frequency of sampling (annual or biannual surveys), number of years sampled, number of points sampled each year, and the \% annual decline one wishes to detect ( $1 \%, 3 \%$, or $5 \%$ ). Analyses are based on available data for each species within each of 6 USFWS Regions in North America. The 7 species for which we conducted power analyses were: LEBI, VIRA, SORA, KIRA, CLRA, AMBI, and PBGR.





1-min subsegment







1-minute sub-segments of survey






Figure 11. Dates of 3 annual survey windows for different areas in North America. The isoclines are based on average maximum temperatures in May, from PRISM at Oregon State University (for the U.S.) and Envfropmple fital caplaida (for Canada).


Survey 1
15 Mar - 31 Mar 1 Apr - 14 Apr 15 Apr - 30 Apr 1 May - 14 May 15 May - 31 May 1 Jun - 14 Jun

Survey 2
1 Apr - 14 Apr
15 Apr - 30 Apr
1 May - 14 May
15 May - 31 May
1 Jun - 14 Jun
15 Jun - 30 Jun

## Survey 3

15 Apr - 30 Apr
1 May-15 May
15 May - 31 May
1 Jun - 15 Jun
15 Jun - 30 Jun
1 Jul - 15 Jul

## Ln(AMBI per Station), national level



3\% change per year (0.03)

$5 \%$ change per year (0.05)


## Bi-annual sampling

1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)



## Ln(CLRA per Station), national level

## Annual sampling

$1 \%$ change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


## Bi-annual sampling

$1 \%$ change per year (0.01)

$3 \%$ change per year (0.03)


5\% change per year (0.05)


$$
\begin{aligned}
& \because \text { Year } 2 \backsim \text { Year } 15 \\
& \curvearrowleft \text { Year } 5 \backsim \text { Year } 20 \\
& \multimap \text { Year } 10 \multimap \text { Year } 30
\end{aligned}
$$

## Ln(KIRA per Station), national level

Annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


## Bi-annual sampling

1\% change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)

$\square$ Year $2 \ldots$ Year 15
$\multimap$ Year $5 \multimap$ Year 20
$\multimap$ Year 10ఊ Year 30

## Ln(LEBI per Station), national level

Annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


## Bi-annual sampling

1\% change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


$$
\begin{aligned}
& \square \text { Year } 2 \ldots \text { Year } 15 \\
& \multimap \text { Year } 5 \multimap \text { Year } 20 \\
& \multimap \text { Year } 10 \multimap \text { Year } 30
\end{aligned}
$$

## Ln(PBGR per Station), national level


$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


## Bi-annual sampling

1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


$$
\begin{aligned}
& \square \text { Year } 2 \ldots \text { Year } 15 \\
& \multimap \text { Year } 5 \multimap \text { Year } 20 \\
& \multimap \text { Year } 10 \multimap \text { Year } 30
\end{aligned}
$$

## Ln(SORA per Station), national level


$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


## Bi-annual sampling

1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


$$
\begin{aligned}
& \ldots \text { Year } 2 \ldots \text { Year } 15 \\
& \multimap \text { Year } 5 \multimap \text { Year } 20 \\
& \multimap \text { Year } 10 \multimap \text { Year } 30
\end{aligned}
$$

## Ln(VIRA per Station), national level

Annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


## Bi-annual sampling

1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


[^0]
## Ln(AMBI per Station), regional level <br> Maximum no. NWRs, maximum mean birds per station

Annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
-- Year 10——— Year 30

## Ln(AMBI per Station), regional level Maximum no. NWRs, minimum mean birds per station

Annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


[^1]
## Ln(AMBI per Station), regional level

Minimum no. NWRs, maximum mean birds per station

Annual sampling
$1 \%$ change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
$1 \%$ change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)

$\square$ Year $2 \multimap$ Year 15
$\multimap$ Year $5 \multimap$ Year 20
$\multimap$ Year $10 \multimap$ Year 30

## Ln(AMBI per Station), regional level

Minimum no. NWRs, minimum mean birds per station

Annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)

—— Year 2 —— Year 15
—— Year $5 —$ Year 20
—— Year 10—— Year 30

## Ln(CLRA per Station), regional level

Maximum no. NWRs, maximum mean birds per station

Annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
—— Year 10—— Year 30

## Ln(CLRA per Station), regional level

Maximum no. NWRs, minimum mean birds per station

## Annual sampling

1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


[^2]
## Ln(CLRA per Station), regional level

Minimum no. NWRs, maximum mean birds per station

Annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


[^3]Minimum no. NWRs, minimum mean birds per station

## Annual sampling

$1 \%$ change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
—— Year 10—— Year 30

Maximum no. NWRs, maximum mean birds per station

Annual sampling
$1 \%$ change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


[^4]
## Annual sampling

$1 \%$ change per year (0.01)

$3 \%$ change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year $5 —$ Year 20
—— Year 10—— Year 30

Minimum no. NWRs, maximum mean birds per station


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


[^5]
## Annual sampling

1\% change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
—— Year 10—— Year 30

Annual sampling
$1 \%$ change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)

$\square$ Year $2 \multimap$ Year 15
$\multimap$ Year $5 \backsim$ Year 20
$\multimap$ Year $10 \multimap$ Year 30

Annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
—— Year 10—— Year 30

## Ln(LEBI per Station), regional level <br> Minimum no. NWRs, maximum mean birds per station

Annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


[^6]
## Annual sampling

$1 \%$ change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
$1 \%$ change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
—— Year 10——— Year 30

## Ln(PBGR per Station), regional level

Maximum no. NWRs, maximum mean birds per station

Annual sampling
$1 \%$ change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
$1 \%$ change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)

$\square$ Year $2 \multimap$ Year 15
$\multimap$ Year $5 \multimap$ Year 20
$\multimap$ Year $10 \multimap$ Year 30

## Ln(PBGR per Station), regional level <br> Maximum no. NWRs, minimum mean birds per station

## Annual sampling

1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
—— Year 10—— Year 30

## Ln(PBGR per Station), regional level <br> Minimum no. NWRs, maximum mean birds per station

Annual sampling
$1 \%$ change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


[^7]
## Ln(PBGR per Station), regional level

## Minimum no. NWRs, minimum mean birds per station

Annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)

$5 \%$ change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 — Year 20
—— Year 10—— Year 30

## Ln(SORA per Station), regional level <br> Maximum no. NWRs, maximum mean birds per station

Annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)

$\ldots$ Year $2 \ldots$ Year 15
$\ldots$ Year $5 \ldots$ Year 20
$\ldots$ Year $10 \ldots$ Year 30

## Ln(SORA per Station), regional level <br> Maximum no. NWRs, minimum mean birds per station

## Annual sampling

1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
—— Year 10—— Year 30

## Ln(SORA per Station), regional level <br> Minimum no. NWRs, maximum mean birds per station

Annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


[^8]
## Ln(SORA per Station), regional level

## Minimum no. NWRs, minimum mean birds per station

Annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
-- Year 10—o- Year 30

Annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
—— Year 10—— Year 30

## Ln(VIRA per Station), regional level

Maximum no. NWRs, minimum mean birds per station

Annual sampling
1\% change per year (0.01)

$3 \%$ change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)

—— Year 2 —— Year 15
—— Year 5 —— Year 20
—— Year 10—— Year 30

Minimum no. NWRs, maximum mean birds per station

Annual sampling
$1 \%$ change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


Bi-annual sampling
$1 \%$ change per year (0.01)


3\% change per year (0.03)

$5 \%$ change per year (0.05)


[^9]
## Ln(VIRA per Station), regional level

Minimum no. NWRs, minimum mean birds per station

Annual sampling
$1 \%$ change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)


Bi-annual sampling
1\% change per year (0.01)


3\% change per year (0.03)


5\% change per year (0.05)

$\square$ Year $2 \multimap$ Year 15
$\multimap$ Year $5 \multimap$ Year 20
$\multimap$ Year $10 \multimap$ Year 30


[^0]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10——— Year 30

[^1]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10—— Year 30

[^2]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10—— Year 30

[^3]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10—— Year 30

[^4]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10—— Year 30

[^5]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10—o- Year 30

[^6]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10—— Year 30

[^7]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10—— Year 30

[^8]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10—— Year 30

[^9]:    —— Year 2 —— Year 15
    —— Year 5 —— Year 20
    —— Year 10—— Year 30

