Population Ecology

Power to Detect Trends in Abundance of Secretive Marsh Birds: Effects of Species Traits and Sampling Effort

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ABSTRACT Standardized protocols for surveying secretive marsh birds have been implemented across North America, but the efficacy of surveys to detect population trends has not been evaluated. We used survey data collected from populations of marsh birds across North America and simulations to explore how characteristics of bird populations (proportion of survey stations occupied, abundance at occupied stations, and detection probability) and aspects of sampling effort (numbers of survey routes, stations/route, and surveys/station/year) affect statistical power to detect trends in abundance of marsh bird populations. In general, the proportion of survey stations along a route occupied by a species had a greater relative effect on power to detect trends than did the number of birds detected per survey at occupied stations. Uncertainty introduced by imperfect detection during surveys reduced power to detect trends considerably, but across the range of detection probabilities for most species of marsh birds, variation in detection probability had only a minor influence on power. For species that occupy a relatively high proportion of survey stations (0.20), have relatively high abundances at occupied stations (2.0 birds/station), and have high detection probability (0.50), ≥40 routes with 10 survey stations per route surveyed 3 times per year would provide an 80% chance of detecting a 3% annual decrease in abundance after 20 years of surveys. Under the same assumptions but for species that are less common, ≥100 routes would be needed to achieve the same power. Our results can help inform the design of programs to monitor trends in abundance of marsh bird populations, especially with regards to the amount of sampling effort necessary to meet programmatic goals.

KEY WORDS marsh birds, monitoring, power analysis, rails, trends, wetland birds, zero-inflated Poisson.

The amount of emergent wetland in North America has declined dramatically since the early 1900s (Tiner 1984). In California, for example, 91% of wetlands have been destroyed (Mitsch and Gosselink 2000). Despite concerted efforts to preserve wetlands, emergent wetlands in the conterminous United States continue to be destroyed, with areal coverage of emergent wetlands declining by 21% between 1950 and 2004 (Dahl 2006). The well-documented loss of these productive and biologically diverse wetlands has led to corresponding declines in abundance and distribution of many taxa that inhabit these ecosystems (Greenberg et al. 2006, Valiela and Martinetto 2007). For example, least bitterns (*Ixobrychus exilis*), American bitterns (*Botaurus lentiginosus*), limpkins (*Aramus guarauna*), king rails (*Rallus elegans*), yellow rails (*Coturnicops noveboracensis*), black rails (*Laterallus jamaicensis*), and several subspecies of clapper rails (*Rallus longirostris*) are listed as federally endangered, threatened, or species of national conservation concern in either Canada, the United States, or Mexico (Committee on the Status of Endangered Wildlife in Canada 2002, Diario Oficial de la Federacion 2002, U.S. Fish and Wildlife Service 2008).

Given the loss of habitat for these marsh-dependent birds and because many are hunted, numerous authors have stressed the need for a continent-wide program to gather information to inform decisions related to conservation and management of secretive marsh birds in North America, including estimating temporal trends in their abundances (Tacha and Braun 1994, Ribic et al. 1999, Conway and Droege 2006, Johnson et al. 2009). The North American Breeding Bird Survey gathers some data on secretive marsh birds, but does not sample emergent wetlands adequately (Bystrak 1981, Robbins et al. 1986, Gibbs and Melvin 1997, Lawler and O'Connor 2004). Further, secretive marsh birds are detected rarely during passive surveys along roadsides because their densities and detection probabilities are often low (Conway et al. 1993, Legare et al. 1999, Bogner and Baldassarre 2002, Conway and Gibbs 2011). To address

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these limitations, a standardized protocol for surveying marsh birds was developed in 1999 that recommended the use of call-broadcast surveys within and adjacent to wetlands to increase detection probability. Survey protocols have been revised annually and have been used at hundreds of locations throughout North America (Conway and Nadeau 2010, Conway 2011). Moreover, a continent-wide sampling design has been proposed (Johnson et al. 2009) and field-tested (M. Seamans, U.S. Fish and Wildlife Service, personal communication). The efficacy of these survey protocols for estimating trends in abundance of populations of secretive marsh birds, however, has not been evaluated.

Long-term monitoring programs designed to estimate trends must be efficient, so that changes in target population parameters can be detected reliably and in sufficient time to develop and implement recovery strategies (Goldsmith 1991, Green and Hirons 1991, Hagan et al. 1992). Therefore, monitoring programs must balance the effort and costs associated with data collection against the risk of failing to detect meaningful trends in the target population parameters (Steidl 2001). Several strategies are available for comparing the effectiveness of alternative sampling strategies, one of which is prospective statistical power analysis. In the context of estimating temporal trends, statistical power is the probability of correctly detecting a trend in a population parameter (Thomas et al. 2004). Power ($1 - \beta$) is the complement of committing a Type II error (β), or failing to detect a genuine trend in a population parameter. If a population is truly declining and that trend goes undetected (i.e., a Type II error is made), consequences for species of conservation concern may be substantial (Steidl et al. 1997). Gauging the power of ongoing monitoring programs to achieve their intended goals, therefore, is a necessary step towards refining sampling designs to increase their effectiveness by ensuring that the probability of detecting trends is as high as possible. Further, comparing power among alternative sampling strategies can help to refine the efficiency of proposed monitoring efforts. Prior to launching a comprehensive monitoring program for marsh birds, Johnson et al. (2009) suggested that a power analysis be performed to evaluate tradeoffs among alternative sampling strategies.

We used data from surveys of marsh birds collected throughout North America between 1999 and 2009 to examine how different amounts and allocations of sampling effort and inherent differences among species affected statistical power to detect trends in abundance. Our goal was to provide general guidance to organizations designing large-scale surveys for marsh birds to help them better meet their programmatic goals, one of which is often to estimate trends in population parameters at regional and continental scales (Tacha and Braun 1994, Ribic et al. 1999, Conway and Droege 2006, U.S. Fish and Wildlife Service 2006).

STUDY AREA

Between 1999 and 2009, marsh birds were surveyed along routes established at the ecotone of emergent wetland vegetation and either the adjacent upland or open water in 37 states in the United States and in Mexico (see Fig. 1 in Conway and Nadeau 2010). Locations for survey routes typically were established by personnel from state and federal resource management agencies who were interested in populations of marsh birds on lands that they managed. Therefore, routes often were established in areas of management interest rather than with a probabilistic sampling scheme that would allow rigorous inferences to a broader target area. Most routes were established on federal lands, especially National Wildlife Refuges, and most surveys were performed voluntarily by agency personnel or volunteers. Vegetation at survey points was dominated by emergent wetland plants, such as cattail (*Typha* spp.), bulrush (*Schoenoplectus* spp.), and cordgrass (*Spartina* spp.).

METHODS

Surveyors followed a standardized protocol to survey marsh birds by broadcasting recorded calls during point-count surveys (Conway 2011). Each surveyor selected a subset of 13 species of marsh birds whose calls they included in their broadcast sequence; surveyors broadcasted calls of all marsh birds with potential to breed in the survey area even when they were interested primarily in results for only 1 species (Conway 2011). The standardized survey protocol consisted of an initial 5-minute passive segment followed by a segment during which recorded vocalizations were broadcast into the marsh. The broadcast segment included a 1-minute period for each species surveyed that was divided into 30 seconds of calls followed by 30 seconds of silence. The overall duration of the broadcast segment of the survey varied among routes because the suite of potential breeders varied among areas. The order in which calls were broadcast was consistent among survey sites (e.g., black rail calls always preceded least bittern calls which always preceded Virginia rail [*Rallus limicola*] calls). Routes were surveyed during mornings (dawn—0959) and evenings (1700—dusk) without precipitation and when wind speed was <20 km/hour. During each survey, surveyors counted birds that they observed or heard calling. Surveyors also noted birds they might have detected at a previous station and when traveling between stations; we excluded these birds from analyses. Stations along each route typically were spaced ≥400 m apart and were always surveyed in the same chronological sequence during either morning or evening survey periods. The suite of 13 species of secretive marsh birds whose calls were potentially included in the broadcast segment of the survey were identified at an interagency workshop by a group of marsh bird experts (Ribic et al. 1999), and included black rails, least bitterns, soras (*Porzana carolina*), yellow rails, Virginia rails, king rails, clapper rails, American bitterns, common gallinules (*Gallinula galeata*), purple gallinules (*Porphyrula martinica*), American coots (*Fulica americana*), pied-billed grebes (*Podilymbus podiceps*), and limpkins (*Aramus guarauna*). Field surveys performed by our employees or us were covered by University of Arizona Institutional Animal Care and Use Protocol number 06-184.

Data Analyses

We use the term "occurrence" to indicate the proportion of survey stations occupied based on presence–absence surveys that were not adjusted for detection probability and "occupancy" to indicate estimates based on presence–absence surveys that were adjusted for detection probability or when presence or absence was known (during simulations). Similarly, we use the phrase "relative abundance" to indicate unadjusted counts of birds detected during surveys and "abundance" to indicate counts of birds that were adjusted for detection probability or when abundance was known (during simulations). We summarized patterns of occurrence and relative abundance for 12 of 13 species of marsh bird listed above by computing the proportion of stations along a route where a species was detected and the mean number of birds detected per survey at each occupied station; we did not have sufficient data to include limpkins. We summarized occurrence of each species by survey route as the proportion of stations where the species was detected 1) for all routes where the species was classified as a probable breeder and therefore included in the broadcast segment of the survey, and 2) for only those routes where the species was detected at least once during the study; these metrics provided slightly different perspectives on distributional characteristics of each species. We summarized relative abundance of each species as the number of detections per station per survey 1) for all stations surveyed and 2) for only the subset of stations where the species of interest was detected at least once. For occurrence data, we treated route as the sample unit, and for relative abundance, we treated station as the sample unit. For summaries of occurrence data, we included routes surveyed ≥ 3 times, and for summaries of relative abundance, we included stations surveyed ≥ 3 times.

We used prospective power analysis to explore how aspects of the sampling design, characteristics of bird populations, and magnitude of trend affected the probability of detecting linear trends in abundance. Specifically, we explored how power changed in response to variation in the proportion of stations occupied by a species, abundance of a species at occupied stations, and detection probability of a species. We explored a range of values that reflected characteristics of bird populations from summaries of field surveys described above and from the literature. Similarly, we explored how power changed in response to varying the number of routes surveyed, the number of stations surveyed per route, the number of surveys (visits) per station per year, and the number of years surveyed.

We estimated power to detect linear trends in abundance with a simulation model that consisted of 3 components: an abundance model, a sampling model, and an analysis model. The abundance model generated an initial distribution of birds across stations on each route based on the levels we established for the proportion of stations occupied and abundance of birds at each occupied station. We modeled abundance of marsh birds with a zero-inflated Poisson model, which is appropriate for count data where zero counts are more common than would be expected under a Poisson model (Lambert 1992). This model reflects survey data that result from a mixture of 2 processes, 1 that describes the distribution of birds across a collection of survey stations (e.g., a survey route) and 1 that describes abundance of birds at survey stations that are occupied. If y_i represents abundance of birds at a survey station i, and P represents the probability that a survey station is occupied, then:

$$y_i \sim \begin{cases} 0 \text{ with probability } 1 - P \\ \text{Poisson}\,(\lambda_i) \text{ with probability } P \end{cases}$$

where λ_i is mean abundance of a species at occupied stations expressed as a Poisson distribution. To establish the distribution and abundance of birds at the start of each simulation, we assigned occupancy of stations along each route based on a random draw from a binomial distribution with probability P, then assigned abundance based on a random draw from a Poisson distribution for P stations and 0 for $1 - P$ stations. To project populations through time, we modeled persistence of birds from 1 year to the next as a random binomial process, with probability of persistence equal to 1 − the target trend (e.g., for a −3% annual trend, the average probability of each bird persisting at a station equaled 0.97).

The sampling model simulated the process of surveying birds at stations. For each survey at each station, we modeled the number of birds a surveyor detected as a random binomial process based on the true number of birds at a station and the probability of detection, which we varied across a range of values representative of marsh birds (0.2–0.6; Alexander 2011, Conway and Gibbs 2011). We accounted for detection probability because it affects power and because detection rates of marsh birds are relatively low and vary among species (Conway and Gibbs 2011). The sampling model yielded counts of birds during surveys that we analyzed with the analysis model.

For the analysis model, we used the log-transformed average number of birds detected per station across all surveys in each year +1 as the response variable. In contrast to log-transformed counts, trends in untransformed counts are less likely to remain linear over time because if the negative trend is constant, annual changes in absolute abundance will decrease over time. For example, if we assume that true abundance (N) is declining at a constant rate of 10% per year and that $N = 100$ at time $t = 0$, then $N = 90$ at $t = 1$ (a loss of 10 individuals) and $N = 81$ at $t = 2$ (a loss of 9 individuals). If a trend is constant, changes in abundance over time will be logarithmic and trends in log-transformed counts will be linear (Hayes and Steidl 1997). An additional advantage of log-transforming counts for analysis is that slope corresponds directly to the rate of change in the population. For example, a slope of −0.03 computed from log-transformed counts indicates an annual rate of change of −3%.

We analyzed simulated survey data with a repeated-measures mixed model with survey route as the primary unit of analysis (subject), which we modeled as a random effect to reflect that we considered routes to represent a sample of all potential routes that could be surveyed, and with year modeled as a fixed effect. To account for the dependence resulting from surveying the same routes each year, we modeled correlations in counts on the same route between years with a first-order autoregressive covariance structure.

We simulated each combination of interest (sampling design, set of population characteristics, and trend) 1,000 times, and computed power as the proportion of times the test for trend (year effect) was rejected correctly. We established power = 0.80 ($\beta = 0.20$) as an arbitrary reference level for acceptable power and fixed $\alpha = 0.05$. Establishing α at a level that might be more appropriate for analysis of monitoring data, such as 0.10, would increase absolute power systematically across all combinations but have no effect on the relative influence of different aspects of the sampling design, which was the focus of our study. Unless we indicate otherwise, we report relative abundance (counts or detections) rather than true abundance because individuals designing monitoring programs for marsh birds are most likely to have information in the form of counts from previous surveys. The number of birds detected during a survey, however, reflects both the true number of birds and detection probability. Therefore, those interested in the levels of true abundance at occupied stations can divide the counts we report by the value we established for detection probability.

RESULTS

Surveyors established 347 survey routes across North America that included 2,900 survey stations, with an average of 8.4 stations per route (SE = 0.21, range = 1–24). Each route was surveyed over an average of 2.8 years (SE = 0.13, range = 1–10) and each station was surveyed an average of 3.3 times in each survey year (SE = 0.02, range = 1–13).

Population characteristics of marsh bird populations varied markedly among target species (Table 1). Across all routes and years surveyed, the proportion of stations where a species was detected during surveys ranged from <0.10 for black rails, yellow rails, king rails, and purple gallinules to 0.26 for clapper rails. Similarly, the number of birds detected per survey at occupied stations spanned an order of magnitude, from 0.27 for black rails to >2.2 for clapper rails and American coots (Table 1). Considering only those routes known to be occupied by a species (i.e., along which the target species was detected at least once), estimates of population characteristics ranged from 1.4 to 17.4 times greater than estimates based on all routes surveyed (Table 1).

Power to detect temporal trends in abundance will be governed by the true size of the temporal trend (Fig. 1). For example, a moderate amount of survey effort (25 routes, 10 survey stations per route, and 3 surveys per station per year) will provide sufficient power to detect annual declines of >4% after 15 years, whereas an annual decline of 2% will require >30 years of surveys for populations where 20% of stations are occupied and 50% of individuals are detected during surveys (Fig. 1). Power to detect trends in abundance will also vary with both characteristics of bird populations and sampling effort. In general, the proportion of survey stations on a route occupied by a species has a greater relative effect on power than does the number of birds detected at occupied stations (Fig. 2A,B). Imperfect detection of birds decreases precision of surveys, which reduces power relative to surveys where detection is perfect (i.e., detection probability = 1.0; Fig. 2C). Across the range of detection probabilities representative of many target species (0.2–0.6; Alexander 2011, Conway and Gibbs 2011), however, variation in detection probability has only a minor influence on power relative to variation in other characteristics of bird populations (Fig. 2).

Altering sampling effort is a primary means surveyors have to influence power, including the number of survey routes, number of survey stations per route, and number of surveys of each station in a year (Fig. 3). To ensure that a monitoring program has sufficient power to detect a target trend, an

Table 1. Mean, standard error (SE), and sample size (*n*) for the proportion of stations per survey route where the species was detected (occurrence) and number of birds detected per station where the species was detected (relative abundance) during surveys of marsh birds throughout North America, 1999–2009. For species occurrences, we based sample sizes on the number of routes surveyed for each species; for relative abundances, we based sample sizes on the number of stations surveyed for each species.

	All stations and routes surveyed[a]						Stations and routes with ≥1 detection[b]					
	Proportion of stations where species was detected/route			No. detections/ station			Proportion of stations where species was detected/route			No. detections/ occupied station		
Species	*n*	Mean	SE	*n*	Mean	SE	*n*	Mean	SE	*n*	Mean	SE
Pied-billed grebe	158	0.22	0.020	1,128	0.42	0.020	103	0.34	0.024	566	0.84	0.030
American bittern	156	0.11	0.014	912	0.22	0.015	74	0.24	0.022	324	0.63	0.033
Least bittern	247	0.19	0.015	1,661	0.27	0.011	163	0.28	0.019	742	0.61	0.019
Black rail	212	0.05	0.007	1,469	0.08	0.005	74	0.14	0.016	415	0.27	0.013
Yellow rail	56	0.02	0.012	402	0.04	0.012	10	0.09	0.062	23	0.65	0.166
Sora	205	0.17	0.015	1,349	0.28	0.016	146	0.23	0.018	610	0.62	0.029
Virginia rail	246	0.16	0.012	1,577	0.27	0.011	178	0.22	0.014	788	0.53	0.019
Clapper rail	202	0.26	0.024	1,294	0.91	0.063	115	0.46	0.031	524	2.24	0.136
King rail	202	0.07	0.012	1,294	0.15	0.013	49	0.27	0.037	227	0.84	0.056
Common gallinule	115	0.10	0.020	831	0.17	0.017	45	0.26	0.041	177	0.80	0.058
Purple gallinule	50	0.08	0.023	422	0.09	0.015	16	0.24	0.054	63	0.63	0.066
American coot	57	0.23	0.042	261	2.17	0.470	29	0.46	0.057	148	3.82	0.804

[a] Includes all routes where the species was classified as a probable breeder and calls for that species were broadcast during surveys, even if the species was never detected along the route during the years surveyed.
[b] Includes only those routes where the species was detected at least once during each year surveyed.

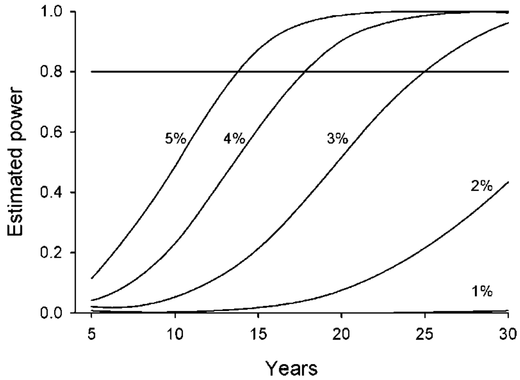

Figure 1. Power to detect linear declines of 1–5% per year in abundance of marsh bird populations over time. Projections based on 25 routes surveyed each year, 10 survey stations per route, 3 surveys per station per year, mean of 20% of stations occupied per route, mean of 1 bird detected per survey at each occupied station, and 0.5 detection probability. For comparison, Bart et al. (2004) proposed that monitoring efforts to detect trends in abundance of land bird populations would be adequate if a sampling design yielded 80% power to detect a 50% decline in abundance within 20 years, which corresponds to an annual rate of decline of approximately 3.5%.

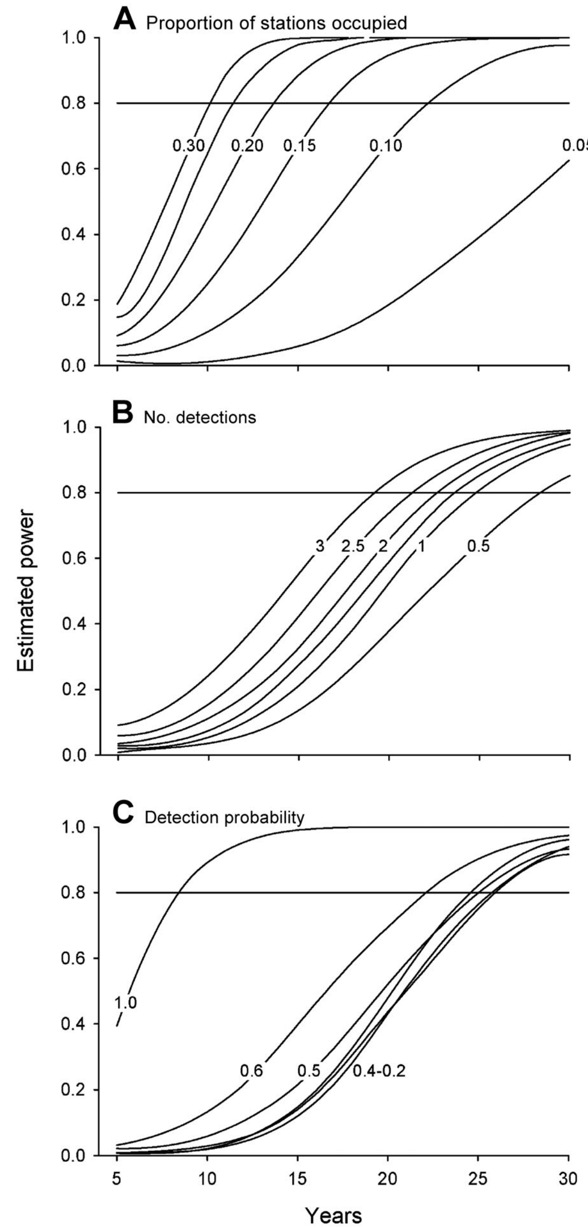

Figure 2. Effects of 3 characteristics of marsh bird populations on power to detect linear trends in abundance: (A) proportion of stations occupied; (B) number of birds detected per survey at occupied stations; and (C) detection probability. Unless a characteristic is varied, projections are based on a 3% annual decrease in abundance, annual surveys, 25 routes, 10 stations per route, 3 surveys per station per year, mean of 20% of stations occupied per route, mean of 1 bird detected per survey at each occupied station, and 0.5 detection probability, except for panel A, which is based on 25 survey stations per route.

adequate number of sampling units (i.e., survey routes) must be established in the area of interest. The minimum number of survey routes required will depend primarily on the size of the target trend to be detected, duration of the study, and population characteristics of target species. Rare species, such as king rails (detected at approx. 7% of stations with an average of 0.84 birds detected per survey at occupied stations; Table 1), would require approximately 100 survey routes to achieve 80% power to detect a 3% annual decline in abundance after 20 years of annual surveys, assuming 0.5 detection probability, 10 stations per survey route, and 3 surveys per station per year (Fig. 3B). In contrast, more common species such as clapper rails (detected at approx. 26% of stations with an average of 2.24 birds detected per survey at occupied stations; Table 1), would require approximately 40 survey routes to achieve the same targets under the same assumptions used in the king rail example (Fig. 3A). Increasing sampling effort by increasing the number of survey stations per route has a stronger influence on power (Fig. 3C) than does increasing the number of surveys per station within a year (Fig. 3D). In general, designing a sampling strategy to achieve a target level of power within a specific time frame will require establishing a level of sampling effort commensurate with the combination of population characteristics of target species in the area of interest (Fig. 4).

DISCUSSION

Characteristics of bird populations have a strong influence on power to detect trends in abundance (Fig. 2); therefore, prior knowledge of the proportion of survey stations likely to be occupied by a target species and the number of birds likely to be detected at occupied stations in the area of interest will help ensure that monitoring programs are designed with sufficient effort to achieve programmatic goals. Because population characteristics vary widely among species (Table 1), the amount of sampling effort required to achieve monitoring goals also will vary by species.

We found that variation in occupancy had a larger influence on power than did variation in abundance of occupied stations when all other factors were held constant (Fig. 2A,B). For a fixed amount of survey effort, when occupancy rates are low—that is, when species are uncommon as are many marsh bird species (Table 1)—surveying more sites less frequently is generally more efficient than surveying fewer sites more frequently; for common species, the opposite allocation is

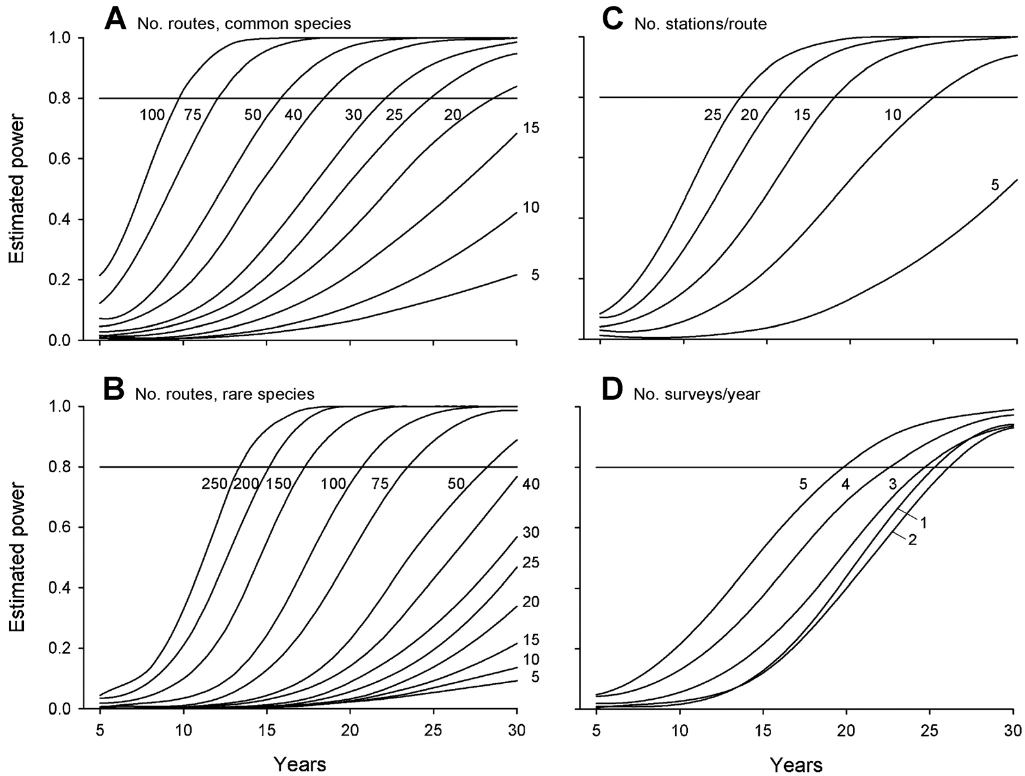

Figure 3. Effects of 3 aspects of sampling effort on power to detect linear trends in abundance of marsh birds: (A) number of survey routes for species with relatively high proportion of stations occupied (0.20), number of birds detected per survey at occupied stations (1.0/survey), and detection probability (0.50); (B) number of survey routes for species with lower proportion of stations occupied (0.08), number of birds detected per survey at occupied stations (0.6/survey), and detection probability (0.20); (C) number of stations per survey route; and (D) number of surveys per station per year. Unless a design feature is varied, projections are based on a 3% annual decrease in abundance, annual surveys, 25 routes, 10 stations per route, 3 surveys per station per year, mean of 20% of stations occupied per route, mean of 1 bird detected per survey at each occupied station, and 0.5 detection probability.

generally more efficient (Field et al. 2005, MacKenzie and Royle 2005). Surveying sites too infrequently, however, incurs a greater loss of statistical power than does surveying too few sites; therefore, having a sufficient number of surveys per site is an important design criterion for monitoring efforts (Field et al. 2005). Ultimately, the most efficient sampling design for a given species will reflect patterns of occupancy and abundance across the area of interest and require balancing the inherent set of trade-offs in temporal versus spatial replication when allocating sampling effort (Bailey et al. 2007).

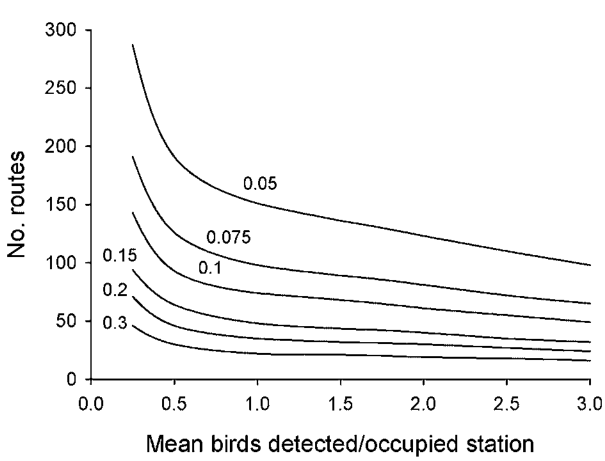

Figure 4. Contours illustrating the effect of varying the proportion of stations occupied (0.05, 0.075, 0.1, 0.15, 0.2, and 0.3) on the number of routes required to achieve 80% power after 20 years of surveys for different numbers of birds detected at each occupied station. Projections are based on a 3% annual decrease in abundance, annual surveys, 10 stations per route, 3 surveys per station per year, and 0.5 detection probability.

Designing monitoring programs to maximize sampling efficiency is especially important for populations of rare species where ensuring sufficient power can be challenging. One strategy to increase power while increasing survey effort only slightly is to increase the number of survey stations along survey routes (Fig. 3C). Although the number of stations that can be surveyed effectively along a route is limited by the narrow time period during mornings and evenings when surveys for marsh birds are most effective (Conway 2011), our results suggest that surveyors should seek to survey as many stations along a route as is feasible during morning and evening survey periods.

Many programs designed to monitor changes in resources across large spatial scales are collections of individual sampling efforts implemented at small scales, such as those designed to assess changes in abundance, distribution, and demography of land birds (DeSante et al. 1995, Bart 2005, Sauer et al. 2011), condition of aquatic resources and wetlands (e.g., Larsen et al. 1995), and natural resources in National Parks (Fancy et al. 2009). Careful coordination of these individual efforts, especially with regards to standardizing survey methods, allows information from smaller-scale efforts to contribute to evaluating changes in abundance, condition, or distribution of resources at larger geographic scales. However, subsets of information gathered at regional or smaller scales are often the highest priority for resource managers (Downes et al. 2005). Therefore, in addition to contributing to broader-scale monitoring goals, smaller-scale monitoring efforts can provide additional benefits to managers, such as the ability to evaluate local trends in occupancy and abundance, species richness, and effects of local management actions. Consequently, monitoring efforts on smaller scales will remain essential to local, regional, and national conservation and monitoring programs, with reliable inferences at smaller scales contingent on how sampling designs are implemented locally.

Because we assumed that species occurrences, abundances, and detection probabilities did not vary systematically across the target survey area, regional variation in these parameters will cause realized power to vary from the values we report. Similarly, because many of the field surveys we summarized reflect characteristics of marsh bird populations in areas of direct management interest (Table 1), estimates we report for some species may differ from those that are likely to result from samples drawn from a wider and more general sampling universe, such as the one described by Johnson et al. (2009). Although these data are the best available, our efforts should be repeated as additional data becomes available, ideally from locations established based on a probabilistic sampling design. In general, if local abundance or occupancy is greater than values we report or if temporal trends are steeper, reasonable levels of power might be attained with less effort than the target levels we established. In contrast, if local parameter values for species or trends are less than we report, sampling effort will need to be increased to achieve the level of power indicated by our simulations. Regardless, the effects of the various design elements on power to detect trend should remain the same, and our conclusions as to which design elements have the largest effect on power should remain valid.

Some authors have questioned the value of omnibus monitoring programs, discouraging so-called "surveillance" monitoring in favor of monitoring only in contexts with narrower, more directed sets of goals (e.g., Yoccoz et al. 2001, Nichols and Williams 2006, Wintle et al. 2010). Others, in contrast, have explored the value of information gained through more general, broad-scale ecological monitoring programs, provided they are developed carefully (e.g., Fancy et al. 2009, Lindenmayer et al. 2012, Noon et al. 2012). Regardless of their impetus, all monitoring programs will benefit when developed to achieve a clear, explicit, and quantitative set of goals that can be used to inform sampling design. Careful design, including attempts to allocate effort optimally, can effectively increase statistical power with little or no increase in sampling effort. For example, if environmental features such as the size of a marsh, whether it is estuarine or palustrine, or whether it is managed or unmanaged, explain heterogeneity in occupancy or abundance of marsh bird populations, then these features can be used to stratify the sampling universe, which will increase precision of estimates and increase statistical power. Additionally, reducing measurement error can increase power. For example, much of the survey data we summarized were gathered by surveyors who were not trained formally to identify all of the vocalizations of the target species of marsh birds. Because observer variation in detections of marsh birds is high for surveyors with little training (Nadeau et al. 2008), increasing training will reduce identification errors and increase statistical power relative to the estimates we report. Lastly, the model we used for analysis reflects the common practice of using counts as the response variable while not adjusting for variation in detection probability. Modeling abundance and the detection process simultaneously, such as within the hierarchical modeling framework (Royle and Dorazio 2008), would likely yield greater power to detect trends.

MANAGEMENT IMPLICATIONS

Although detecting temporal trends in abundance may be only 1 of many goals for regional- or continental-scale monitoring programs for marsh birds, factors that influence power to detect trends in abundance likely will be relevant when designing sampling efforts to address other questions about abundance of marsh bird populations. Because multiple species of marsh birds often inhabit the same area, we suggest that sampling effort be established to meet programmatic goals for the rarest species of interest. This will ensure that statistical power to detect trends for more common species will be high and will likely provide reliable estimates at even finer spatial scales, such as the state or regional level. Developing sampling designs to achieve target levels of statistical power for the rarest species, however, will demand higher levels of sampling effort than for common species. Nonetheless, given that the rarest species of marsh birds are also likely to be the most vulnerable, allocating sufficient effort to detect trends in populations of the rarest species in time to take management action to prevent extinction seems like a high priority for long-term monitoring efforts. Similarly, evaluating effects of management actions on the rarest species of marsh birds will likely be a higher priority than for more common species. As a general guideline, our results indicate that monitoring programs with a goal of detecting trends in abundance of marsh birds should aim to establish at least 100 survey routes with as many stations per route as is logistically feasible in areas of breeding habitat for target species to ensure that biologically meaningful trends in abundance can be detected for the species of greatest conservation concern. Sampling 100 survey routes 3 times per year for marsh birds requires a modest amount of effort that can be accomplished by 5 technicians working for 2.5 months.

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