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ARTICLE

Summary of Intrinsic and Extrinsic Factors Affecting Detection Probability of Marsh Birds

Courtney J. Conway · James P. Gibbs

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Abstract Many species of marsh birds (rails, bitterns, grebes, etc.) rely exclusively on emergent marsh vegetation for all phases of their life cycle, and many organizations have become concerned about the status and persistence of this group of birds. Yet, marsh birds are notoriously difficult to monitor due to their secretive habits. We synthesized the published and unpublished literature and summarized the factors that influence detection probability of secretive marsh birds in North America. Marsh birds are more likely to respond to conspecific than heterospecific calls, and seasonal peak in vocalization probability varies among co-existing species. The effectiveness of morning versus evening surveys varies among species and locations. Vocalization probability appears to be positively correlated with density in breeding Virginia Rails (*Rallus limicola*), Soras (*Porzana carolina*), and Clapper Rails (*Rallus longirostris*). Movement of birds toward the broadcast source creates biases when using count data from call-broadcast surveys to estimate population density. Ambient temperature, wind speed, cloud cover, and moon phase affected detection probability in some, but not all, studies. Better estimates of detection probability are needed. We provide recommendations that would help improve future marsh bird survey efforts and a list of 14 priority information and research needs that represent gaps in our current knowledge where future resources are best directed.

Keywords Bitterns · Call-broadcast · Monitoring · Rails · Tape-playback · Vocalization probability

Introduction

Many species of marsh birds in North America have declined within at least some portion of their geographic range (Eddleman et al. 1988; Conway and Sulzman 2007; Sauer et al. 2008). Consequently, many species are listed as endangered, threatened, or species of concern in Canada, the U.S., or Mexico (U.S. Fish and Wildlife Service 2008, 2011; COSEWIC 2010). However, rigorous estimates of population trend are not available for many marsh birds because: 1) the North American Breeding Bird Survey does not adequately sample emergent wetlands (Gibbs and Melvin 1993; Lawler and O'Connor 2004), and 2) they are rarely detected visually. Many organizations have recently become concerned about the persistence of species that inhabit these ecosystems because the quality and quantity of wetlands have continued to decline. For example, the acreage of emergent wetlands declined 21% between 1950 and 2004 in the United States (Dahl 2006). For these reasons, a continental monitoring program that focuses on marsh birds has been proposed for North America (Ribic et al. 1999) and progress has been made recently to develop standardized survey methods for such a program (Conway and Gibbs 2001; Conway and Droege 2006; Conway 2009).

One reason why many organizations have suggested a separate monitoring program that focuses on marsh birds is the low detection probability associated with standard

C. J. Conway (✉)
U.S. Geological Survey, Arizona Cooperative Fish and Wildlife Research Unit, 325 Biological Sciences East,
School of Natural Resources and the Environment,
University of Arizona,
Tucson, AZ 85721, USA
e-mail: cconway@usgs.gov

J. P. Gibbs
Environmental and Forest Biology, State University of New York,
1 Forestry Drive,
Syracuse, NY 13210, USA

survey methods. Hence, identifying the factors that influence detection probability is important for designing future survey efforts, modifying existing survey protocols, and comparing results among studies. Numerous published papers have examined one specific issue (i.e., the effects of call-broadcast on detection probability of one or more species), often within one region of the country. However, we lack a single paper that summarizes the results of these species-specific, issue-specific, or area-specific studies and provides a synthesis of these topics for resource managers and scientists. To address this need, we conducted an exhaustive review of published and unpublished literature. Our goal was to summarize what we know (and do not know) about the intrinsic and extrinsic factors that influence detection probability of secretive marsh birds. We provide recommendations for designing marsh bird survey efforts, and list questions that require further study to help guide investigators and students wishing to contribute to marsh bird monitoring and management.

Methods

We conducted an extensive literature review, and located 49 published manuscripts and 35 unpublished reports that included results of surveys for North American marsh birds. In 2000, we also sent letters to approximately 200 authors who had published papers on marsh birds over the past 30 years requesting unpublished reports on local or regional marsh bird survey efforts. From these sources, we summarized the intrinsic and extrinsic factors that influence vocalization probability of marsh birds to aid in development of a common standardized survey protocol. We excluded papers or reports that were based on low sample sizes or unsubstantiated conclusions (see Conway and Gibbs 2001 for a summary of the more obscure papers and reports).

Results

Methods for conducting marsh bird surveys were not standardized until recently (Conway and Gibbs 2001; Conway 2009). Past survey efforts differed substantially in the number of focal species, duration of point-count survey, distance between adjacent survey points, number of counts at each point per yr, survey radius, and the time of day and the season of the year when observers conducted surveys (Conway and Gibbs 2001). The average number of birds detected per point varied among species (0.0–2.0 birds/point), and survey efforts reported large variation in the maximum distance at which observers were able to detect birds (80 to >1,000 m). Observers detected most (73%–100%) birds aurally rather than visually (Conway and Gibbs 2001; Conway et al. 2004). The seasonal peak in number of birds detected varied among marsh bird species and even among locations within species (as early as mid-March and as late as the end of July; Conway and Gibbs 2001). Some of these issues cannot be entirely standardized among surveys that take place across an entire continent, but improvements to standardization should be implemented. Many past studies identified factors that influence detection probability of marsh birds; these issues are summarized in the following sections.

Effects of Call-broadcast

In comparison to passive surveys, call-broadcast surveys increased vocalization probability of Black Rails (*Laterallus jamaicensis*), Yellow Rails (*Coturnicops noveboracensis*), Soras (*Porzana carolina*), Virginia Rails (*Rallus limicola*), King Rails (*Rallus elegans*), Clapper Rails (*Rallus longirostris*), Common Moorhens (*Gallinula chloropus*), Purple Gallinules (*Porphyrula martinica*), American Coot (*Fulica americana*), Limpkins (*Aramus guarauna*), Wilson's Snipe (*Gallinago delicata*), and Pied-billed Grebes (*Podilymbus podiceps*) (Erwin et al. 2002; Lor and Malecki 2002; Allen et al. 2004; Conway et al. 2004; Conway and Gibbs 2005; Pierluissi 2006; DesRochers et al. 2008; Soehren et al. 2009; Conway and Nadeau 2010). In contrast to the species above, studies reported conflicting results regarding the effectiveness of call-broadcast at increasing vocalization probability of the bitterns. Call-broadcast increased the number of American Bitterns (*Botaurus lentiginosus*) detected by 240% in South Dakota (Allen et al. 2004), and by 295% and 52%–59% in New York (Conway and Gibbs 2001; Lor and Malecki 2002), but did not increase numbers detected in other studies (Cashen 1998; Conway and Gibbs 2005; Conway and Nadeau 2010). Similarly, call-broadcast increased vocalization probability of Least Bitterns (*Lxyobrychus exilis*) by 140% and 80% in New York (Swift et al. 1988; Bogner and Baldassarre 2002) and by 750% in Maine (Gibbs and Melvin 1993), but had little effect in other studies (Cashen 1998; Lor and Malecki 2002; Conway and Gibbs 2005; Tozer et al. 2007; Soehren et al. 2009; Conway and Nadeau 2010). More thorough study of regional variation in the effectiveness of call-broadcast for detecting Least Bitterns and American Bitterns is warranted.

Estimates of Detection Probability

Few unbiased estimates of detection probability are available for marsh birds (Conway and Gibbs 2001). Past authors report estimates of detection probability of marsh birds based on several different methods, but few have incorporated observer error (i.e., the failure of a surveyor to record a bird that vocalized during the survey; Conway and

Simon 2003). The percentage of territorial pairs responding to call-broadcast surveys varied from 20%–100% for Soras and 22%–72% for Virginia Rails (Glahn 1974). However, Glahn (1974) did not describe the method used to estimate the number of territorial pairs. The percentage of focal birds that vocalized during a survey differed between male (93%) and female (21%) Common Moorhens (*Gallinula chloropus*) based on 28 pairs with known locations (Brackney and Bookhout 1982).

The percentage of radio-marked birds that are detected during a call-broadcast survey can overestimate vocalization probability because an observer will likely assume that the radio-marked bird vocalized if another bird vocalizes that is very close to the radio-marked bird. However, we believe that this approach likely has less bias than other approaches. Vocalization probability during the breeding season differed between male (50%) and female (20%) radio-marked Black Rails in Florida (Legare et al. 1999). Vocalization probability of radio-marked Yuma Clapper Rails (19% across seasons) varied seasonally, and was highest (40%) during the early breeding season (Conway et al. 1993). Vocalization probability of radio-marked birds in New York was 31% for American Bitterns (Conway and Gibbs 2001) and 25.5% for male Least Bitterns (Bogner and Baldassarre 2002).

Numerous authors have compared the numbers of marsh birds recorded during aural surveys to other indices of population size: number of nests found (Mangold 1974; Zembal and Massey 1981; Brackney and Bookhout 1982; Lor 2000; Pierluissi 2006), the number of breeding territories estimated via spot-mapping (Griese et al. 1980), or the number of individuals captured (Tacha 1975; Kwartin 1995). Correlations between counts from aural surveys and other population indices are difficult to interpret because a correlation (or lack of correlation) between two indices tells us nothing about the correlation between either index and true abundance.

Observer Bias

Observer bias is an important component of detection probability (Conway and Simon 2003), but few studies have estimated observer bias associated with marsh bird surveys. The average observer detection probability (the percent of birds made available that are actually detected by a surveyor) for Black Rails during call-broadcast surveys in Arizona was 76% but varied among three observers from 61%–85% (Conway et al. 2004). Observer detection probability varied among co-existing species (from 45% for Least Bitterns to 65% for Clapper Rails) and was higher on the call-broadcast segment of the surveys compared to the passive segment of the surveys for one (Clapper Rails) of six species examined (Conway and Nadeau 2006). Observers differed in their ability to hear Clapper Rail calls in New Jersey and Least Bitterns in New York (Mangold 1974; Swift et al. 1988). Further work is needed to examine the factors that influence observer bias during marsh bird surveys and the effectiveness of training at reducing that bias.

Variation in Detection Probability

The few available estimates indicate large temporal variation in number of marsh birds detected (Griese et al. 1980; Conway and Gibbs 2005; Conway and Nadeau 2006). The use of call-broadcast seems to help; temporal variation in number of birds detected was lower on call-broadcast surveys than on passive surveys (Flores and Eddleman 1991; Conway et al. 2004; Conway and Gibbs 2005; Conway and Nadeau 2006). We need more estimates of temporal and spatial variation in detection probability associated with both passive and call-broadcast surveys of marsh birds to better assess the benefits of call-broadcast surveys relative to passive surveys.

Time of Day

Quantifying variation in detection probability throughout the day is important for adopting optimal survey windows for a standardized continental monitoring program. Previous marsh bird surveys have been conducted in the morning, in the evening, at night, or throughout the day (Conway and Gibbs 2001). Morning or evening surveys are considered best for most marsh birds (except perhaps Yellow Rails and eastern Black Rails which may call more at night). Evening surveys have proven better in some studies (Johnson and Dinsmore 1986; Flores and Eddleman 1991; Tango et al. 1997 [Least Bitterns]; Conway et al. 2004), whereas morning surveys were better in others (Tango et al. 1997 [all species except Soras and Least Bitterns]; Cashen 1998; Legare et al. 1999; Nadeau et al. 2008). Other studies reported no difference between morning and evening counts (Tacha 1975; Marion et al. 1981; Kwartin 1995; Spear et al. 1999; Tecklin 1999). Soras and Virginia Rails vocalized more readily during morning surveys in late April and May in Missouri, but vocalized more readily during evening surveys in early June (late incubation and brood-rearing; Johnson and Dinsmore 1986). Observers detected more Soras during nighttime surveys during the migration season, but detected similar numbers during morning and nighttime surveys during the breeding season in Maryland (Tango et al. 1997).

The time of day when vocalization probability is highest can vary among locations and also among co-existing species at the same location. The peak in number of Black Rails detected during morning surveys in Arizona was 0600–0659 (Conway et al. 2004). The daily peak in the number of birds detected was 0400–0600 for American Bitterns and Virginia Rails, 0600–0800 for Pied-billed Grebes, and 0800–1000 for Least Bitterns and Soras in Maine (Gibbs and Melvin 1993). Optimal weather conditions for conducting surveys appear to be better in the morning in some regions (Baird 1974; Todd 1980; Conway et al. 2004), but better in the evening in others (Mangold 1974). Sound interference from other birds is typically lower in the evening (Mangold 1974; Johnson and Dinsmore 1986), but loud choruses of anurans can reduce detection probability of marsh birds during evening and nighttime surveys in some regions (Runde et al. 1990).

Seasonal Peak in Vocalization Probability

Vocalization probability during call-broadcast surveys typically varies throughout the breeding season (Glahn 1974; Tacha 1975; Johnson and Dinsmore 1986; Conway et al. 1993; Spear et al. 1999; Bogner and Baldassarre 2002; Tozer et al. 2006; but see Brackney and Bookhout 1982; Tecklin 1999). Times of year when observers detected the most birds during surveys varied greatly among locations (Conway and Gibbs 2001). For example, the seasonal peak in number of Black Rails counted was April-early May in New Jersey (Kerlinger and Wiedner 1991), late May-late June in Arizona (Repking and Ohmart 1977; but see Flores and Eddleman 1991), and late July in Florida (Legare et al. 1999). The seasonal peak in number of Virginia Rails counted was 15–30 April in Kansas (Tacha 1975), the 3rd week of May in Wisconsin (Manci and Rusch 1988), and late May-early July in Maine (Gibbs and Melvin 1993).

The seasonal peak in vocalization probability can differ among co-existing species in the same marsh (Gibbs and Melvin 1993; Conway and Gibbs 2001; Rehm and Baldassarre 2007). For example, seasonal peak in numbers of birds detected was not consistent across study areas or between Virginia Rails and Soras within the same study area in Colorado (Griese et al. 1980). Observers in northeastern New York detected the highest numbers of American Bitterns in late April through mid-May, but detected the highest numbers of Least Bitterns in late May through early July (Rehm and Baldassarre 2007). Seasonal peak in numbers detected was not consistent among marshes even within the same year (or among year in the same marsh) for Black Rails (Flores and Eddleman 1991; Conway et al. 2004), Clapper Rails (Zembal and Massey 1987), and other marsh birds (Rehm and Baldassarre 2007).

Many studies have reported two seasonal peaks in number of birds detected (Pospichal and Marshall 1954; Kaufmann 1971; Glahn 1974; Flores and Eddleman 1991; Tango et al. 1997; Legare et al. 1999). The second peak may be caused by: 1) second broods or re-nesting attempts; 2) juvenile birds beginning to vocalize; 3) an influx of migrants, or 4) adults attempting to teach calls to young birds. Conducting surveys multiple times per year (at regular intervals during the breeding season) will help ensure that surveys are conducted during the time of year when vocalization probability is highest for all co-existing species in each area. Multiple surveys at each point during each year can also help ameliorate the problems associated with high day-to-day variation in vocalization probability that has been reported for many species of marsh birds (Zembal and Massey 1987; Tango et al. 1997; Conway et al. 2004). Three or more counts per year at each point would also allow analysts to monitor trends in occupancy (MacKenzie et al. 2002). Three counts per year at each survey point have been recommended by previous investigators (Gibbs and Melvin 1993; Tozer et al. 2006; Conway 2009). However, one count per year at each point would allow more routes to be sampled for a given amount of sampling effort. Prospective power analyses (Steidl et al. 1997) are needed to help identify the best solution to this tradeoff.

Seasonal peak in number of Soras and Virginia Rails detected differed by 1–2 weeks between two consecutive years in Minnesota, Missouri, and Wisconsin (Pospichal and Marshall 1954; Johnson and Dinsmore 1986; Manci and Rusch 1988). Seasonal peak in the number of Black Rails detected during call-broadcast surveys differed by 1 month across 2 years in Arizona (Flores and Eddleman 1991). Peak in Soras detected during weekly fall surveys was 2–3 weeks apart in two consecutive years in Maryland (Kwartin 1995). Seasonal peak in numbers of marsh birds detected differed between two consecutive years in Kansas (Baird 1974; Tacha 1975) and Maryland (Tango et al. 1997). Using the average number of birds detected (or the maximum detected) on a survey route across numerous counts per year to estimate population trend can help ameliorate biases created by annual variation in the seasonal peak in vocalization probability.

Variation Among Stages of the Breeding Cycle

Stage of the breeding cycle influenced vocalization probability of Soras (Kaufmann 1971), Virginia Rails (Kaufmann 1971; Glahn 1974), and radio-marked Black Rails (Legare et al. 1999). Vocalization probability during call-broadcast surveys was high during early breeding in Spotless Crakes (*Porzana tabuensis*), but was near zero once incubation began (Kaufmann 1988). Additionally, the proportion of Least Bitterns in New York that responded to call-broadcast was 47% during nest initiation, but dropped to 11% during incubation and hatching (Bogner and Baldassarre 2002). Vocalization probability peaked during the week prior to egg laying in Virginia Rails (but not in Soras; Kaufmann 1971). Many species appear to cease calling after egg-laying (Pospichal and Marshall 1954; Kaufmann 1988; Bogner and Baldassarre 2002). Non-nesting radio-marked Black Rails had higher vocalization probability (60%) compared to nesting birds (46%) in the same marsh (Legare et al. 1999). Ideally, marsh bird surveys in a local area should be timed to ensure that at least one survey coincides with the typical dates of peak clutch initiation for each co-existing species of marsh birds in the local area. Even still, the best approach for dealing with such variation in detection probability is to design a survey protocol that provides estimates of detection probability (or at least one or more components of detection probability) as part of the actual counts.

Effects of Weather and Environmental Factors on Vocalization Probability

Identifying factors that cause variation in detection probability is useful because they can be incorporated into analyses to improve estimates of population trend as well as potentially reduce sampling effort needed to reliably estimate trend. Weather conditions are often assumed to influence vocalization probability of marsh birds. However, the proportion of temporal variation in vocalization probability of marsh birds explained by weather variables varied greatly among studies. Temporal and environmental variables explained 3%–18% of the variation in number of Black Rails responding to call-broadcast surveys in Arizona (Flores and Eddleman 1991), 15%–20% of the variation in number of Black Rails responding to call-broadcast surveys in California (Spear et al. 1999), and 39%–46% of the variation in number of Virginia Rails detected in Maryland (Tango et al. 1997). Weather conditions did not help explain variation in the number of Soras detected during fall surveys in Maryland (Kwartin 1995). The effects of weather on vocalization probability appeared to vary among coexisting species of marsh birds in the same location and to vary among studies for the same species. Day-to-day variation in detection probability appears to be very high for many species of marsh birds (Zembal and Massey 1987; Tango et al. 1997; Conway et al. 2004) and this temporal variation is only partially explained by weather variables.

Most past studies have reported no effect of ambient temperature on vocalization probability (Conway and Gibbs 2001), but ambient temperature is correlated with time of day and season of the year (both of which affect vocalization probability) and past studies have failed to control for time of day and season of the year when examining the effects of ambient temperature. Moreover, the relationship between vocalization probability and ambient temperature may not be linear; hence, models that assume underlying linear relationships between temperature and numbers of birds detected may obfuscate important relationships. Wind velocity was most often negatively correlated with vocalization probability, but some studies reported no effect of wind (Conway and Gibbs 2001). Only a few studies mentioned specific wind speeds that negatively affected vocalization probability: >8 kph (Mangold 1974; Tacha 1975) and >16 kph (Smith 1974). Wind velocity also influenced the distance at which surveyors can hear calls; even a light breeze reduced the distance at which surveyors could hear Yellow Rails by a factor of two or more (Bart et al. 1984). The effect of percent cloud cover and rainfall on vocalization probability of marsh birds was equivocal. High tides in California reduced calling activity of Clapper Rails (Zembal and Massey 1987) and Black Rails (Spear et al. 1999). Number of Black Rails detected on call-broadcast surveys was positively related to moon light the preceding night in California (Spear et al. 1999), but lunar phase explained little of the variation in number of Black Rails detected in Arizona (Flores and Eddleman 1991). Virginia Rails vocalized more often during darker phases of the moon during one year (but not the next) in Maryland (Tango et al. 1997). More thorough studies are needed on the effects of weather, tide stage, and moon phase (while controlling for season and time of day) on detection probability of marsh birds.

Effects of Density on Vocalization Probability

Vocalization probability of radio-marked Black Rails during call-broadcast surveys varied between study sites (29% vs. 62%) in Florida (Legare et al. 1999). This spatial variation in vocalization probability may be caused by variation in breeding density and this relationship deserves further study. Vocalization probability appears to be positively correlated with breeding density in Virginia Rails (Glahn 1974), Soras (Kaufmann 1971), and Clapper Rails (Zembal and Massey 1981, 1987), but not in Common Moorhens (Brackney and Bookhout 1982). A positive correlation between vocalization probability (or other components of detection probability) and breeding density is problematic because it causes estimates of population change (declines and increases) to be overestimated. Studies are needed to estimate the strength of correlation between density and vocalization probability, to determine whether passive or call-broadcast surveys produce count data that are less affected by breeding density, and whether surveyors can effectively count individuals when densities are high.

Duration of Survey Period

Duration of counts has varied greatly among past marsh bird survey efforts: from 1 to 46 min (Conway and Gibbs 2001). Moreover, past survey efforts varied in whether they included a passive period prior to, or after, the call-broadcast period (Conway and Gibbs 2001). Longer counts at a point result in more birds detected (higher detection probability), but the rate of new detections declines with each passing min. Moreover, a longer count results in fewer points surveyed within the relatively narrow window of time when vocalization probability is high each day, so there is a trade-off between how long to survey at a given location and the number of locations that are visited. Most studies report a rather rapid decline in new detections over the course of the survey period even for survey periods lasting only 5–6 min (Glahn 1974; Johnson 1984; Cashen 1998; Legare et al. 1999; Conway et al. 2004; but see Bogner and Baldassarre 2002).

Call-broadcast of Conspecific Calls Versus Heterospecific Calls

Most studies reported that marsh birds vocalize most frequently in response to conspecific broadcast compared to heterospecific broadcast sequences (Tacha 1975; Johnson and Dinsmore 1986; Gibbs and Melvin 1993; Allen et al. 2004; Pierluissi 2006; Soehren et al. 2009; Conway and Nadeau 2010). But studies vary in how vocalization probability is affected by heterospecific call-broadcast. For most marsh bird species examined in an extensive analysis of data from throughout North America, observers detected more individuals during the broadcasted calls of one or more co-existing species compared to passive segments of the survey (Conway and Nadeau 2010). In contrast, broadcasting only Black Rail calls decreased detection probability by an average of 21% relative to passive surveys for four coexisting species of marsh birds in Arizona (Conway et al. 2004). Vocalization probability of Least Bitterns in New York did not appear to be affected by the broadcast of other species' calls (Swift et al. 1988). And regional dialects may influence response to call-broadcast; call-broadcast increased detection probability for the subspecies of Common Moorhen in Hawaii (*Gallinula chloropus sandvicensis*) when surveyors broadcasted local calls but not when they broadcasted calls from the mainland subspecies (*Gallinula chloropus cachinnans*) (DesRochers et al. 2008). Other studies report that some (but not all) species vocalize equally in response to conspecific and heterospecific calls (Glahn 1974; Johnson and Dinsmore 1986; Tango et al. 1997; Allen et al. 2004). Virginia Rails (but not Soras) commonly responded to Black Rail calls in northern California (Tecklin 1999), and responded equally to both conspecific calls and calls of other marsh birds in Maryland (Tango et al. 1997). In particular, King Rails and Clapper Rails (Tango et al. 1997; Conway and Nadeau 2010), and Soras and Virginia Rails (Tacha 1975; Johnson and Dinsmore 1986; Cashen 1998; Allen et al. 2004) appear to respond readily to each other's calls.

An important consideration is whether broadcasting conspecific and heterospecific calls decreases detection probability compared to a survey which includes only conspecific call-broadcast. Relative to surveys using only conspecific calls, broadcasting both Clapper Rail and Black Rail calls in Arizona increased the number of Black Rails detected (Todd 1980) and had no effect on the number of Clapper Rails detected (Conway and Nadeau 2006). And the number of birds detected during heterospecific broadcast segments was similar to or higher than the number detected during initial passive segments (those prior to the start of call-broadcast) for 13 species of marsh birds (Conway and Nadeau 2010). Hence, inclusion of numerous species' calls in a broadcast sequence apparently does not negate the effectiveness of conspecific call broadcast. Moreover, the chronological order in which species' calls are broadcast during surveys did not influence vocalization probability of Soras or Virginia Rails in Missouri (Johnson and Dinsmore 1986), nine species of secretive marsh birds in Maryland (Tango et al. 1997), or Common Moorhens in Hawaii (DesRochers et al. 2008).

Broadcast Volume

Past survey efforts have differed widely in the type of broadcast equipment used (Conway and Gibbs 2001). Most survey efforts conducted prior to 2000 used small handheld tape cassette players with a "powerhorn" attached, but some used similar equipment without a powerhorn. Most studies failed to report the broadcast volume used during surveys and whether or not any attempt was made to standardize broadcast volume. Broadcast volume varied from 72–96 dB at 1 m in front of the speaker for the studies that reported volumes (Conway and Gibbs 2001). The number of Black Rails detected did not differ between paired surveys broadcasting calls at 80 dB (1 m from the source) versus those broadcasting calls at 90 dB in Arizona (Conway et al. 2004). The effect of broadcast volume on detection probability of marsh birds may vary among species, regions, and habitat conditions; this issue warrants more thorough study.

Type of Calls

Most studies failed to report the type(s) of calls included in their broadcast sequence (Conway and Gibbs 2001). Many past survey efforts used only one call type (the most common call) of each species. The type of call(s) included in the broadcast sequence may affect detection probability (Cashen 1998; Tecklin 1999; DesRochers et al. 2008; but see Kwartin 1995). For example, *grr* calls given by Black Rails typically cannot be heard by observers beyond 30 m but *kic-kic-kerr* calls can be heard over 100 m away (Tecklin 1999; Conway et al. 2004). Including all common call types in the call-broadcast sequence for each target species may increase detection probability given that specific calls are given more frequently during different stages of the breeding cycle (Zembal and Massey 1987; Conway et al. 2004). Many species of rails give paired duets. We know little about whether or not including paired duets in the broadcast sequence affects detection probability of rails. Choice of calls to include in standardized broadcast sequences needs more study.

Effect of Call-Broadcast on Bird Movement

One approach for estimating population density (distance sampling) requires that surveyors estimate the distance to each bird detected. Systematic movement of birds toward or away from the surveyor prior to detection violates a critical assumption of distance sampling (Buckland et al. 1993). Data from call-broadcast surveys are even more likely to violate this assumption than data from passive surveys because numerous authors have reported that birds moved toward the broadcast source prior to vocalizing (Weske 1969; Smith 1974; Tacha 1975; Legare et al. 1999; Tecklin 1999; Bogner and Baldassarre 2002; Lor and Malecki 2002). Unpaired Clapper Rails approached the broadcast much more readily than did paired birds in Arizona (Smith 1974). Male Black Rails were more likely to move toward the broadcast than were females (Legare et al. 1999).

Discussion

Survey methods, survey duration, call-broadcast volume, types of calls used for broadcast, and equipment used on past marsh bird survey efforts varied greatly. Implementation of a standardized survey effort is underway (Conway 2009; Johnson et al. 2009) that will allow comparison across studies and create the ability to pool data for regional and continental analyses. Our synthesis of past marsh bird studies provides a summary of our current knowledge of 14 important issues that help inform optimal design of marsh bird monitoring efforts. This exercise was useful because it helped identify lingering research needs (Table 1), the answers to which would further inform decisions regarding future marsh bird survey efforts. A thorough summary such as this also allowed us to make informed recommendations on survey methods (Table 1) that will allow future analysts to control for many of the issues raised in this paper.

Standardization of marsh bird survey methods is needed at regional, continental, and international scales to facilitate interpretation of data, allow cross-study comparisons, and permit pooling of data for large-scale analyses. Pooled databases that are freely available for download via the internet would improve data sharing and facilitate analyses to increase our understanding of the factors affecting marsh bird detection probability and improve our ability to estimate population trends. Efforts to achieve these goals

Table 1 List of the priority research needs, information needs, and survey recommendations for the improvement of marsh bird monitoring, from highest to lowest priority.

Research Needs
1. Extent to which detection probability is positively correlated with population density in each species of marsh bird
2. Whether the extent of correlation between detection probability and population density differs between passive surveys and call-broadcast surveys
3. Bias and precision of distance estimates (and the factors that influence bias and precision of those estimates) that are specific to marsh birds
4. Effect of tide stage on detection probability of birds in coastal marshes
5. Effects of broadcasting different call types on detection probability and whether effectiveness of different call types changes seasonally
6. Effects of broadcasting different regional dialects on the effectiveness of call-broadcast
7. Effects of chronological order of species within broadcast sequence on detection probability
8. Whether observer bias differs between passive surveys and call-broadcast surveys
9. Effects of broadcast volume (for each call type) on the extent to which call-broadcast increases detection probability in marsh birds
10. Effect of weather conditions on vocalization probability of marsh birds based on a large dataset whereby the influence of ambient temperature (and other weather variables) can be examined after controlling for the correlated effects of time of day and season of the year
Information Needs
1. Power analyses to determine the number of survey points or routes needed to detect specific rates of population change over different time intervals for each species of marsh bird and to help clarify the benefits and drawbacks of 1 vs 3 counts per year at each station
2. Optimal time(s) of day when surveys should be conducted in each region and for each species
3. Optimal dates when surveys should be conducted in each region and for each species
4. Quantify the effectiveness of surveyor training on detection probability of, and distance estimation to, marsh birds
Survey Recommendations
1. Include ≥3 counts each year at each survey point
2. Collect data so that detection probability can be estimated within the sampling program to account for temporal, spatial, and observer variation

are currently underway; see Conway (2009) and the following two websites: http://ag.arizona.edu/srnr/research/coop/azfwru/NationalMarshBird/ and http://www.pwrc.usgs.gov/point/mb/. Great progress has been made during the past 10 years to improve marsh bird monitoring efforts and to begin implementation of a continental monitoring program for marsh birds in North America. We believe that further improvements can be made by following the recommendations in Table 1 and by continuing to promote interagency collaboration in establishing a continental marsh bird monitoring program.

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