Occupancy and Detection Probabilities of Secretive Marsh Birds in the Kissimmee Chain of Lakes, Florida

by

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Abstract

Loss of marsh habitat has led to population declines of many species of North American marsh birds. However, due to the secretive nature of many of these species there is uncertainty about their population. Recently developed techniques such as the North American Marsh Bird Monitoring Protocol (NAMBMP) and occupancy analysis can be used to improve both the quality and quantity of information we have about secretive marsh birds. In 2009 and 2010, we conducted point counts of black rail (*Laterallus jamaicensis*), least bittern (*Ixobrychus exilis*), king rail (*Rallus elegans*), purple gallinule (*Porphyrio martinica*), and limpkin (*Aramus guarauna*) using the NAMBMP in the Kissimmee Chain of Lakes, Florida. We investigate the factors influencing detection and occupancy probability using competing robust design occupancy models in program MARK. We found that detection probability varied with temperature and Julian day for least bitterns, cloud cover and Julian day for purple gallinule, survey location for limpkin, and vegetation cover and detections at the previous point sampled for king rails. Occupancy probability varied with vegetation height for least bitterns, floating vegetation for purple gallinules, vegetation density for limpkins and vegetation density and floating tussocks for king rails. Conserving for diverse assemblages of marsh habitats will support the greatest diversity of secretive marsh birds.

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I: INTRODUCTION

The wetland habitats of the Kissimmee Chain of Lakes (KCOL) have been significantly altered from their historical state. Changes to the system, including altered water regimes, nutrient loading from increased human activity, and loss of surrounding wetland ecosystems have resulted in greater trophic levels and increased growth of native and exotic macrophytes. Beginning as early as the 1880's there were efforts to channelize waterways and drain wetland habitats leading to more useable land (Blake 1980). It became increasingly desirable to control water levels to protect against high water events as human population increased. By the mid 1960's, much of the water fluctuations in the KCOL were effectively controlled (Wegener et al. 1974).

Water control measures greatly altered the natural water regimes in the KCOL by eliminating natural highs and low water events that acted on this system. Historically, these lakes and surrounding wetlands acted as natural reservoirs. In the wet season water would collect and overflow into surrounding lands creating broad marshy wetlands (SFWMD et al. 2008). Conversely, in the dry season many of these wetlands and shallower portions of lakes would dry out facilitating the consolidation and oxidation of bottom sediments and preventing buildup of excess organic material (SFWMD et al. 2008).

There was also an increase in point and nonpoint source nutrient loading. Sewage treatment plants began discharging into the surrounding watershed in the 1940s (Wegener et al. 1974) and increased agricultural activities lead to greater nonpoint source nutrient runoff. Nutrient influxes were magnified because the natural filtration system provided by surrounding wetlands was bypassed by channelized waterways (SFWMD et al. 2008).

Effects of water level control and increased nutrient inputs on the KCOL were quickly realized by lake managers. By 1970, only 6 years after completion of the water control structures on Lake Tohopekaliga, managers began to notice adverse effects on the lake ecosystem (Holcomb and Wegener 1971). Periodic drawdowns, so that littoral zones were not covered by water, were recommended to reduce some of these adverse effects (Wegener and Williams 1975). Drawdowns began in 1971 and beginning in 1987, were combined with mechanical muck and vegetation removal and experimental use of herbicides (Moyer et al. 1995, FFWWCC 2004). Early results, such as increased sport fish and macroinvertebrate populations, along with an increase in desirable plant communities and recreational access, were quickly realized but habitat alterations where short-lived (Holcomb and Wegener 1971, Wegener et al. 1974, Wegener and Williams 1975, Allen 1999, FFWCC 2004). Later results showed increased longevity of habitat alterations, but also showed mixed results in fish, invertebrate, and plant communities (Butler et al. 1992, Moyer et al. 1995, Allen et al. 2003, Bonvechio 2006). The last lake drawdown was conducted on Lake Tohopekaliga in 2004, and local treatment of littoral vegetation with herbicide is conducted annually (SFWMD et al. 2008).

Studies have examined how lake restoration projects affect trophic status, vegetation, invertebrates and fish populations, but few studies have investigated effects on other species of wildlife. In fact, the state of Florida requested that the FWC conduct more rigorous studies to examine how these projects affect local wildlife populations

(Office of Program Policy Analysis and Government Accountability 2001). For the 2003-2004 Lake Tohopekaliga project there was research looking at pre and post treatment populations of water birds, vegetation communities, and aquatic vertebrates (Muech 2004, Welch 2004, Brush 2006, Kitchens et al. 2008). However, birds such as king rail (*Rallus elegans*), limpkin (*Aramus guarauna*), least bittern (*Ixobrychus exilis*), purple gallinule (*Porphyrula martinica*), and black rails (*Latterallus jamaicensis*) were not sampled adequately by the techniques used in these studies. These birds are seldom seen and only infrequently call so they are much more adequately surveyed using call broadcast surveys (Gibbs and Melvin 1993, Conway et al. 2004, Conway and Gibbs 2005). Little is known about how these birds might be affected by management activities on the KCOL.

Secretive marsh birds depend on types of habitat that are most affected by lake management practices such as tall, dense stands of emergent vegetation (i.e., *Typha* spp., *Scirpus* spp*., Pontederia cordata*). King rails and least bitterns use dense monotypic stands of tall emergent vegetation for most of their life cycle (Poole et al. 2005, Poole et al 2009). Limpkins use dense emergent vegetation for feeding and brood rearing (Bryan 2002), and purple gallinules use them partially for feeding and breeding (West and Hess 2002). Some rail species have been known to use emergent stands with vegetation mats or tussocks. For example, Virginia rails (*Rallus limicola*) have used water up to 1 m deep for feeding because the effective water depth averaged 12 cm due to floating mats of vegetation (Billard 1947).

Many secretive marsh birds are being placed on state and federal watch lists because of population declines (Conway 2009). Specifically for the KCOL, black rails and limpkins were listed as Birds of Conservation Concern by the U.S. Fish and Wildlife Service (2008). In addition, black rails and king rails are listed as management priorities because they have special management challenges, such as special habitat requirements and low detection rates (U.S. Fish and Wildlife Service 2005). Loss of habitat is frequently cited as a major reason for declines of secretive marsh bird populations (Eddleman 1988, Conway et al. 1994, Conway et al. 2004). Loss of emergent wetlands is nowhere more evident than in the KCOL. Much of the land between the lakes of the KCOL would have historically been inundated for part of the year and would be classified as wetlands. The broad shallow wetland areas between the lakes created by seasonal high water would have provided dense, diverse stands of emergent vegetation with varying shallow water levels that seem to be ideal for secretive marsh birds. Since the areas between the lakes are now converted to other uses, lake littoral zones could be important habitat for secretive marsh birds.

If these birds are extirpated from central Florida there could be impacts to local ecosystems in addition to local economies. These birds are of value to the local economy since they are valued to bird watchers, and their presence increases the overall value of the KCOL as part of a lucrative wildlife viewing business in Florida. In 2006 1.6 million people participated in wildlife viewing, and of these 1.3 million were bird watchers (Florida Fish and Wildlife Conservation Commission 2008). Those wildlife viewers as a whole spent $3 billion in the state, which compares well with other wildlife related activities such as hunting ($3.6 billion) and fishing ($4.5 billion; U.S Dept of Interior et al. 2006).

Little is known about the specific habitat needs of secretive marsh birds in the KCOL and even less is known about how lake management practices could affect them. Therefore, research should investigate the habitat associations of secretive marsh birds. Lake managers can then use this information to better plan for this group of birds when considering management alternatives for the KCOL. In an effort to provide better information about marsh bird habitat use in the littoral zones of the KCOL we initiated a study in the spring of 2009 and 2010. In this study we used the North American Marsh Bird Monitoring Protocol (Conway 2009) along with robust design occupancy models (Mackenzie et al. 2003) to collect data and provide more reliable information about habitat requirements of secretive marsh birds in the KCOL.

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CHAPTER II: FACTORS INFLUENCING DETECTION PROBABILITY OF SECRETIVE MARSH BIRDS ON THE KISSIMMEE CHAIN OF LAKES, FLORIDA

ABSTRACT

There is uncertainty about the population status of secretive marsh birds in North America. Many species are thought to be declining, but data generally are lacking to assess their population status. Lack of data is due to inadequate sampling techniques and low and variable detection probabilities. The North American Marsh Bird Monitoring Protocol (NAMBMP) was recently developed to increase number of detections and account for variability in detection probabilities between sampling occasions. In 2009 and 2010, we conducted point counts of black rails, least bitterns, king rails, purple gallinules and limpkins using the NAMBMP in the Kissimmee Chain of Lakes, FL. We assessed the effectiveness of call-broadcasts to elicit detections and investigated factors influencing detection probabilities using competing robust design occupancy models in program MARK. Effects of call-broadcasts on number of detections varied by species Least bitterns and purple gallinules had smaller increases in the number of detections after the call broadcast than king rails and limpkins. The relationship between detection probability and factors thought to influence detection probability varied by species. The highest ranking detection model for least bittern indicated that detection probability declined with cooler days earlier in the year and hot days later in the year. The best purple gallinule model predicted that cloud cover influenced the positive relationship between detection probability and Julian date, while detection probability varied by study

site in the best limpkin model. The king rail model comparison contained more uncertainty but vegetation cover (*w* = 0.61) and detection at the previous point sampled (*w* = 0.26) had the greatest parameter likelihoods. With the use of both techniques future research could improve the reliability of data and improve understanding of population trends of secretive marsh birds.

INTRODUCTION

Many species of secretive marsh birds are thought to be declining and have been designated as species of concern (Butcher et al. 2007, USFWS 2005, 2008). However, there is uncertainty about the population status of secretive marsh bird due to low and variable detection rates and inadequate sampling techniques (Cooper 2008, USFWS 2008, Conway 2009, Poole et al. 2009). Without reliable information, managers and policy makers are hampered in making decisions about conservation and management of these species.

Efforts to monitor bird populations, such as the Breeding Bird Survey and passive point counts, may not adequately sample marsh bird populations. Marsh habitats are inadequately sampled by the Breeding Bird Survey (Bystrak 1981, Gibbs and Melvin 1993, Conway and Gibbs 2005), and passive point counts may not adequately sample species of secretive marsh birds because they have inherently low detection rates (Gibbs and Melvin 1993). Some studies have estimated that between 25-50% of birds present are not detected (Conway and Nadeau 2006, Nadeau et al. 2008), and these detection rates can vary between sampling events (Conway and Gibbs 2011). Even in species that are more conspicuous, detection rates can vary with ambient sound, observer, local weather conditions, characteristics of the bird, and habitat (Simons et al. 2007). Failure to account for low and/or variable detection rates can lead to unreliable population estimates and inferences about habitat use (Thompson 2002, Gu and Swihart 2004, Mackenzie et al. 2006).

Researchers traditionally standardized survey methods to help limit variability in detection and treated counts as indices of the true population (Nichols et al. 2000). The North American Marsh Bird Monitoring Protocol (NAMBMP) was developed to improve information about secretive marsh bird populations using standardized data collection methods and call-broadcasts of focal species to limit the variation in detection probability and increase detection rates (Conway 2009). However, standardized methodologies alone cannot account for variability in detection probabilities that arise from differences in variable like behavior, and habitat (Johnson 1995). Fortunately, the NAMBMP also allows for the use of many recently developed techniques such as distance sampling (Buckland et al. 2001, Rosenstock et al. 2002), double observer (Nichols et al. 2000, Alldredge et al. 2006) and occupancy analysis (MacKenzie et al. 2006). Detection probabilities estimated using these techniques can be used to adjust raw count data and reduce bias due to detectability (Alldredge et al. 2006).

Occupancy analysis uses presence/absence data from multiple site visits to estimate the probability of detecting the species (Mackenzie et al. 2006). An assumption of single season occupancy analysis is that the population is closed to changes between site visits. Therefore, single season occupancy models are very sensitive to population changes due to local colonization or extinction events occurring between sampling occasions (Rota et al. 2009). Multi-season or robust design occupancy was developed to account for local colonization and extinction events (Mackenzie et al. 2003). The sampling scheme is based on Pollock's (1982) robust design for mark-recapture survival studies. Sampling events are divided into primary periods between which the population is allowed to change, and secondary periods that are closed to changes in occupancy (Mackenzie et al. 2003).

In this study we used NAMBMP to collect point count data on black rails (*Laterallus jamaicensis*), least bittern (*Ixobrychus exilis*), king rail (*Rallus elegans*), purple gallinule (*Porphyrio martinica*), and limpkin (*Aramus guarauna*) in the Kissimmee Chain of Lakes, FL. We used a robust design occupancy analysis to estimate detection probabilities and investigate factors influencing detection probabilities of these species.

METHODS

Study Area

The Kissimmee Chain of Lakes (KCOL) is a series of interconnected shallow lakes in central Florida (28 4'N 81 19'W). The five largest of these lakes are Lake Kissimmee (12,913 ha) Lake Tohopekaliga (7,615 ha), Lake Hatchineha (6,629 ha), East Lake Tohopekaliga (4,470 ha), and Cypress Lake (1,635 ha). These lakes are highly valued for recreation and vary in the degree of shoreline development from undeveloped natural areas to pasture and suburban housing. Stabilized water levels due to water control structures and increased nutrient inputs from agriculture and other developments have encouraged the growth of thick stands of emergent littoral vegetation (Holcomb and Wegener 1971). These stands consist primarily of cattail (*Typha spp.)* bulrush (*Scirpus validus)* pickerelweed (*Pontederia cordata*), and spatterdock (*Nuphar lutea*).

Marsh Bird Surveys

We established point count locations (Lake Kissimmee, n=66; Lake Tohopekaliga, n=46; Lake Hatchineha, n=27; East Lake Tohopekaliga, n=30; Cypress Lake, n=17) along the edge of littoral vegetation. Points were established by selecting a random starting point with subsequent points placed about 400 m apart to limit double counting of individuals. Surveys were conducted following the NAMBMP (Conway 2009). This protocol consists of a 5 min passive listening period followed by five 1-min periods of 30 seconds of playback and 30 seconds of listening for each focal species. We chose black rail, least bittern, king rail, purple gallinule and limpkin as focal species because they were thought to historically breed in the area (Bryan 2002, West et al. 2004, Poole et al. 2005, Poole et al. 2009). The order of call-broadcasts was by ascending level of intrusiveness (i.e. Black Rails are least intrusive followed by least bittern, king rail, purple gallinule and limpkin; Conway 2009). Point counts were conducted 4 times each year at each location in Feb - May 2009 and 2010, began 30 min before sunrise and were typically completed by 2.5 hr after sunrise (Nadeau et al. 2008) and were not conducted in periods of high wind (>15 Km/h), or precipitation. In our sampling design, primary periods were site visits and secondary periods were simultaneous point counts by two observers. Observers were trained to identify focal species by sight and sound.

Influence of Call-Broadcast

We investigated the effect of call-broadcasts on the number of detections because our survey protocol used call-broadcasts to elicit more detections. In our study, we were primarily interested with patch occupancy and not abundance of a species. For that reason a species only needs to be detected once during each point count to be counted as detected. Therefore, we divided the point counts into 10 1-min segments and recorded when the initial detection of the species occurred during the point count. We examined the pattern of initial detections and when they occurred during the 10-min count to discern whether call-broadcasts were an effective tool at eliciting new detections, or just re-detections of species already accounted for.

Detection Parameters

We gathered data on local weather, timing of point counts, observer effort and habitat parameters to assess factors affecting secretive marsh bird detection rates. Wind speed (WIND, Km/h), air temperature (TEMP, °C), were the average of values measured at the first and last point count conducted each day. We recorded ambient noise (NOISE; 0-4, Conway 2009), cloud cover (CLOUD; clear/few clouds, partly cloudy, and overcast) and time to/from sunrise (TTS, hr) at each point count. We also gathered vegetation data at each point count location. Percent vegetation cover (%VEGCOVER) was the average percent cover of 25 plots ($1m^2$) within 100 m of each point count location. These data were collected once for each point count location at the end of the season in the 2009 and 2010, to limit the disturbance to resident birds and habitat. We estimated percentage of area within 100 m of the point that was classified as emergent vegetation (%EMERGENTVEG), using a digitized map of littoral vegetation (Avinon Inc. 2009, Dewberry 2010), and Fragstats 3.3 (McGarigal and Marks 1995). Digitized vegetation maps where based on 0.30m resolution aerial photos taken in 2007 (East Lake Tohopekaliga) and 2009 (Lake Kissimmee, Lake Tohopekaliga, Cypress Lake and Hatchineha). Detection probability may vary with year (YEAR), lakes (LAKE), Julian date (DOY) and point count observer (OBS) so we also included these variables. We included a prior detection variable (PRIOR) because observers may be more likely to detect a species at a location if it has already been detected during previous site visits (Riddle et al. 2010). It is also possible that bird detections were spatially correlated and detections at the previous point sampled are related to detections at the current point; especially for louder birds such as limpkins. Therefore, we included a variable that indicated whether the species was detected during the sampling period at the point visited before the current point (p(t-1); Betts et al. 2008).

Data Analysis

We used robust design occupancy models to estimate detection probabilities (Mackenzie et al. 2003). Analysis was performed using RMark (Version 2.0.1, Laake 2010) which is a package for R (Version 2.12.1, R Development Core Team 2010) that constructs models for program MARK (Version 6.0, White and Burnham 1999). Robust design occupancy estimates initial site occupancy (ψ), and local colonization probability (γ), local extinction probability (ε) between primary periods and detection probability (p) for each secondary period. We were primarily interested in occupancy probability, and not the process of local extinction and colonization, so we used an alternate parameterization that estimates detection, occupancy and extinction probability (Mackenzie et al. 2003). This parameterization estimates detection probabilities for each secondary period and occupancy probability for each primary period and still allows for changes in occupancy between primary periods, but with fewer parameters. We held occupancy and local extinction constant to compare competing detection probability models. We considered a total of 41 models base on *a priori* hypotheses of the effects of weather, observer, effort and habitat parameters (see Appendix A for list of all models considered). Models considered were limited to models with fewer parameters to limit the number of parameters in future occupancy models. Models were ranked using models weights based on Akaike's information criterion adjusted for small sample size (AIC_c) (Anderson et al. 2000). We calculated parameter estimates using model averaging based on AIC_c model weights for all candidate models (Anderson 2008).

RESULTS

We visited and completed point counts at each location on 4 occasions in each of 2 years (n=1488 site visits; n=2976 point counts). We had 2525 total detections of focal species at those points for an average of 0.78 detections per point in 2009, and 0.70 in 2010. We did not detect Black Rails during our surveys. The number of individual detections per point varied by species, survey round and lake (Table 1). We had a greater average detection probabilities for purple gallinule (0.57 ±0.024 SE) least bittern (0.64 ±0.025 SE) and limpkin (0.58 ±0.024 SE). However, king rails had much lower average detection probability (0.034 ±0.012 SE).

Call-broadcasts had different effects on the focal species (Fig 1). Only king rail displayed an increase in the proportion of detections during the total five minute call-broadcast period (61%) when compared to the initial passive period (39%). Least bittern (41%), purple gallinule (37%), and limpkin (40%) all had lower proportions of detections during the call-broadcast period than during the passive listening period. However, the proportion of total detection did increase during each conspecific call-broadcast period in all four species. This increase varied by species with king rails (39.39%) having the largest increase followed by limpkins (22.96%), purple gallinules (19.27%) and least bitterns (14.73%). Percentage of initial detections that occurred before their conspecific call-broadcast varied among species: least bittern 63.7%, king rail 45%, purple gallinule 78%, and limpkin 77%.

For 3 of 4 species there was a clear highest ranking detection model with over 95% of the AIC_c weight. The highest ranking model for least bittern includes an interaction between DOY and TEMP (Table 2). This model predicts that least bitterns had greater detection probabilities on warmer days early in the year, and cooler days later in the year than cool days early in the year and warm days later in the year (Table 3, Fig 1). The interaction between CLOUD and DOY was the highest ranking model for purple gallinule (Table 3, Fig 2). This model predicts that partly cloudy skies had lower detection probability than overcast conditions early in the year and greater detection probabilities later in the year, while clear skies have the lowest detection probability early in the year and detection probabilities close to partly cloudy later in the year. The highest ranking model for limpkin included LAKE (Table 2). Detection probabilities were higher on Lake Hatchineha, East Lake Tohopekaliga, and Lake Tohopekaliga, than on Lake Kissimmee or Cypress Lake (Table 3). We considered a subset of 14 simpler models for king rails, because of a lack of detections. Model selection had more uncertainty than for the other species. Of the 13 models considered 9 made up 95% of the AIC_c weight (Table 2). We used model averaging to account for this variability and found that parameter likelihoods were greatest for %VEGCOVER (0.60), and p(t-1) (0.25); however 95% confidence limits for β included 0 for all parameters (Table 4).

DISCUSSION

We found that the use of call-broadcasts increased the number of initial detections for all species considered, however, the magnitude of this increase varied by species. Call-broadcasts have long been used to elicit responses by birds that have low detection rates (Conway and Gibbs 2005). There are potential drawbacks to this method, including habituation to calls, decreased detection of coexisting species, disturbance to birds, and variation due to broadcast equipment and calls used (Conway and Gibbs 2005). However, most studies support the use of call-broadcasts to increase detection rates (e.g., Allen et al. 2004, Conway and Gibbs 2005, Conway and Nadeau 2010). We found that call-broadcasts had the least influence on least bitterns, which is consistent with other studies. Least bitterns had a relatively small increase in detections in an analysis of data collected throughout North America (Conway and Nadeau 2010), and in other studies the influence of call broadcast on least bitterns was mixed (Bogner and Baldassarre 2002, Lor and Malecki 2002). Purple gallinules showed similar response to least bitterns. There have been fewer studies on the response of purple gallinules to call-broadcasts but generally there is an increase in the number of detections when they are used (e.g., Soehren et al. 2009, Conway and Nadeau 2010, Conway and Gibbs 2011). King rails had the greatest response to our call-broadcast, results that are well supported in the literature (Conway and Nadeau 2010, Conway and Gibbs 2011). However, there were relatively few king rail responses during our survey efforts. Limpkins showed the next greatest response with a 22% increase from the previous minute. The use of call-broadcasts with limpkins is not well documented; however our results showed that call-broadcasts could be a useful tool to increase the probability of detecting limpkins during point counts. Whereas call-broadcasts did increase the number of detections for all species considered, many of these species would have high detection rates without call-broadcasts (Fig 1.). Only king rails had more detections occurring during the call-broadcast period, than in the passive phase.

For other species >60% of initial detections occurred before call-broadcasts began. With recently developed analysis techniques to account for low and variable detection probabilities, (e.g. occupancy analysis), the lower number of detections that would come with not using call-broadcasts may be acceptable, and the possible negative effects of call-broadcasts would be avoided. In addition, any parameter estimates related to detection probability become contingent on the use of call-broadcasts, since they were used to increase the number of detections. Results using call-broadcasts will not be comparable to studies that don’t utilize call-broadcasts. Future research may need to consider whether the use of call-broadcasts is worth the potential adverse effects and the loss of comparability of estimated detection parameters to other studies.

We found that detection probabilities for marsh bird species were influenced by different factors. The highest ranking model for detection of least bitterns included an interaction between temperature and Julian date. This model predicts that this species was more likely to be detected on warmer days early in the season than on warmer days later in the season. Many studies have reported relationships between temperature and bird calling and detection rates (Robbins 1981, Verner 1985). However, temperature has had mixed results for secretive marsh birds. Some studies reported a strong positive relationship (e.g. Spear et al. 1999) but others report little to no relationship (Conway and Gibbs 2001). Bird calling activity also has been well documented to increase during the breeding season (e.g. Best 1981, Wilson and Bart 1985), and secretive marsh birds seem to follow that trend (Conway and Gibbs 2001, Bogner and Baldassarre 2002, Conway and Gibbs 2011).

The highest ranking detection model for purple gallinule included an interaction between cloud cover and Julian date. Detection probability increased as Julian date increased. However, detection probability increased at different rates through the year with different levels of cloud cover. Other studies have shown weak relationships between detection and cloud cover (e.g. Robbins 1981). Black rails (*Laterallus jamaicensis*), another species of secretive marsh bird, had a negative relationship with cloud cover in another study (Spear et al. 1999). However, most studies report no correlation with cloud cover (Tacha 1975, Lagare et al. 1999). The influence of weather conditions on secretive marsh bird detection generally varies between studies (Conway and Gibbs 2011). The interaction between cloud cover and Julian date has not been documented with secretive marsh birds. We did find that heavy cloud cover was correlated with lower detection probabilities later in the year but it also was correlated with the highest detection probabilities earlier in the year. This relationship may be influenced by the thunderstorms that are typical of the wet season of late spring and summer in central Florida and that detection probabilities are lower on days with thunderstorm conditions in area. Earlier in the year this interaction may be driven by warmer temperatures in the early morning due to overnight cloud cover, however a model that included an interaction between Julian date and temperature did not receive much weight in our analysis.

We found strong support that detection rates of limpkins are different between sampling locations. We were much more likely to detect limpkins on Lake Tohopekaliga, East Lake Tohopekaliga, and Lake Hatchineha than other lakes (Table 5). We also detected more limpkins per point on lakes with the greatest detection probabilities (Table

1). Detection probability can be a function of population density (Royle and Nichols 2002, Conway and Gibbs 2011). Snail kite (*Rostrhamus sociabilis*) populations are also more abundant on East Lake Tohopekaliga and Lake Tohopekaliga when compared to other lakes in the KCOL (Reichert et al. 2011). Since limpkins and snail kites are both dependent on apple snail (*Pomacea* spp.) populations (Sykes et al. 1995, Bryan 2002) the increase abundance of both species on these lakes suggests that apple snails are possibly more available on theses lakes leading to greater abundances and detection probabilities.

Few king rails were detected, and model selection for king rails contained more uncertainty than other species. We found that parameter likelihoods were greatest for average vegetation cover and detections at the point previously surveyed. Many points where king rails were detected had dense vegetation in comparison to points without king rail detections. A model that predicts a relationship between dense vegetation and detection probability would be confounded with the fact that most king rails occupied only these points with dense vegetation. In addition, there were few areas that we sampled on the KCOL with large dense stands of vegetation that supported king rails, and most of the detections of king rails only occurred in these few areas. Detections at the previously sampled point could be due to the arrangement of habitat and not necessarily due to king rails calling at previously sampled points increasing calling rates at the current point. More detections of king rails over a large range of weather and seasonal variables would help decipher whether there is a real relationship between vegetation density and previous detections or whether this is an artifact of the nature of our data.

Our data did not support some other commonly supported ideas about marsh bird detection probabilities. Differences in the ability of observers to detect a species have long been known (Ronsenstock et al. 2002) and observer efficacy can change during a study (Norvell et al. 2003). Surveys for secretive marsh bird also suffer from differences in observer ability (e.g., Nadeau et al. 2008, Darrah and Krementz 2009, Rush et al. 2009). However, we found that observer models were not among the top models considered. Since observers conducted counts simultaneously in our study there were no confounding effects of sampling at different times. These differences, such as different calling call rates, exact locations of birds in relation to the point, and various densities of individuals, which could change between site visits, could greatly alter the availability of species for detection by different observers if they visit the point at different times. In addition, we were only concerned with species detections, and observer differences may be amplified when abundance of a species is considered. We also found little support for wind speed, local noise levels, and time of day influencing the detection probability of secretive marsh birds. The NAMBMP encourages participants to limit the effect of these parameters by not conducting point counts when wind or noise levels would hinder auditory detections of birds, and most point counts were completed within 3.5 hours of sunrise so the effect of these variables were probably limited by the protocol.

SUGGESTIONS FOR FUTURE SURVEY EFFORTS

We used a combination of a standardized methodology and occupancy analysis to account for low and variable detection probability of secretive marsh birds. Call broadcasts increased the number of detections; however the usefulness of these increases may be limited in studies that are primarily interested in species occupancy and account for detection probability. Seasonal timing, weather conditions and differences between study sites should be considered when conducting point counts. Cooler conditions early in the year and hotter conditions later in the year should be considered along with factors such as rain or high wind when deciding to conduct point counts. Accounting for differences in detection probability due to differences between study sites along with seasonal timing and weather and would improve detection models. Yearly average detection probability was over 0.99 for these species (Mackenzie et al. 2006: $p^{*}=1-(1-p)^{k}$), suggesting that fewer surveys would be acceptable. For species with greater detection rates surveys could be timed to coincide with the local breeding seasons and fewer point counts would be needed. However, some species may have low detection probability, in which case longer sampling periods would be advantageous. In addition, studies with numerous species may benefit from longer sampling periods to better capture different seasonal peaks in detection probability. Future survey efforts should critically consider the potential use of call-broadcasts to increase the number of detections. By surveying during appropriate time periods and weather conditions and using analysis methods to account for detection probability, future research should be able to account for low and variable detection probabilities associated with secretive marsh birds.

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Table 1. Mean (SE) number of secretive marsh birds recorded per point, by species, month and location on the Kissimmee Chain of Lakes, FL 2009 and 2010. Data reported are from double observer point counts.

	n	Limpkin n= 1300	Least bittern n=1273	Purple gallinule n=1130	King rail n=39	Total n=3742
Round						
1st	744	0.36 (0.03)	0.04 (0.01)	0.10 (0.01)	0.007 (0.003)	0.51 (0.03)
2nd	744	0.49 (0.03)	0.33 (0.02)	0.19 (0.02)	0.023 (0.008)	1.04 (0.05)
3rd	744	0.45 (0.03)	0.72 (0.04)	0.55 (0.03)	0.016 (0.005)	1.73 (0.06)
4th	744	0.45 (0.03)	0.61 (0.04)	0.67 (0.04)	0.007 (0.003)	1.75 (0.06)
Lake						
Cypress Lake	272	0.13 (0.03)	1.03 (0.08)	0.10 (0.03)	0.018 (0.008)	1.26 (0.10)
Lake Hatchineha	432	0.38 (0.04)	0.43 (0.04)	0.14 (0.02)	0.030 (0.012)	0.98 (0.06)
Lake Tohopekaliga	736	0.69 (0.04)	0.49 (0.03)	0.24 (0.02)	0.008 (0.003)	1.42 (0.06)
Lake Kissimmee	1056	0.16 (0.02)	0.27 (0.02)	0.71 (0.03)	0.011 (0.004)	1.16 (0.05)
East Lake Tohopekaliga	480	0.89 (0.05)	0.33 (0.03)	0.25 (0.02)	0.006 (0.004)	1.47 (0.08)

Table 2. Model selection results of robust design occupancy detection probability (*p)* models of secretive marsh birds in the Kissimmee Chain of Lakes, Florida. Models making up >95% of AICc weights (w_i) are listed.

Model [a]	$\mathrm{AIC_c}$ [b]	$\Delta\mathrm{AIC_c}$ [c]	$\mathrm{w_i}$ [d]	Deviance	*K* [e]
Least bittern					
Ψ (.)ε (.) p (TEMP + DOY + TEMP * DO)	2378.57	0	1	2366.1	6
King rail					
Ψ (.) ε (.) p (%VEGCOVER)	333.41	0	0.6	325.41	4
Ψ (.) ε (.) p (p(t-1))	335.15	1.74	0.25	327.154	4
Ψ (.) ε (.) p (DOY)	338.45	5.04	0.05	330.452	4
Ψ (.) ε (.) p(.)	340.75	7.34	0.02	334.748	3
Ψ (.) ε (.) p(%EMERGENTVEG)	342.36	8.95	0.01	334.359	4
Ψ (.) ε (.) p(NOISE)	342.39	8.98	0.01	334.387	4
Ψ (.) ε (.) p(YEAR)	342.72	9.31	0.01	334.716	4
Purple gallinule					
Ψ (.) ε (.) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	2180.48	0	0.96	2163.67	8
Limpkin					
Ψ (.) ε (.) p (LAKE)	2661.62	0	1	2647	7

[a] DOY = Julian date, LAKE = East Lake Tohopekaliga, Lake Tohopekaliga, Cypress Lake, Lake Hatchineha, Lake Kissimmee. HCLOUD = Overcast. MCLOUD = Partly cloudy NOISE = subjective scale from 0-5 of noise level at point count. p(t-1) = detection of species at last point visited. %EMERGENTVEG = % of area classified as emergent vegetation. %VEGCOVER = average percent cover by emergent vegetation at 25 plots ($1\mathrm{m}^2$) within 100 m of point count location. TEMP = Average temperature (°C) of first and last point sampled each morning, YEAR = 2009 or 2010.

[b] $\mathrm{AIC_c}$ = Akaike's information criterion corrected for small sample size.

[c] $\Delta\mathrm{AIC_c}$ = difference in $\mathrm{AIC_c}$ relative to the smallest value

[d] w_i = $\mathrm{AIC_c}$ model weights, [e] *K*=Number of parameters.

Table 3. Parameter estimates (β), standard errors (se) and 95% confidence limits of detection probability models in the Kissimmee Chain of Lakes, Florida. Estimates are based on AIC_c best ranked detection (*p*) models in program MARK. Occupancy (Ψ) and local extinction (ε) were held constant in all models considered.

	Parameter[a]	β	se	LCL	UCL
least bittern					
ψ	intercept	-0.456	0.08	-0.612	-0.3
ε	intercept	-0.214	0.112	-0.434	0.005
p	intercept	-13.784	1.516	-16.756	-10.812
	DOY	0.163	0.02	0.125	0.201
	TEMP	0.585	0.08	0.429	0.741
	DOY:TEMP	-0.006	0.001	-0.008	-0.005
purple gallinule					
ψ	intercept	-0.43	0.098	-0.622	-0.238
ε	intercept	-0.679	0.145	-0.964	-0.395
p	intercept	-3.196	0.546	-4.265	-2.126
	DOY	0.048	0.006	0.036	0.059
	MCLOUD	0.878	0.51	-0.121	1.878
	HCLOUD	-2.352	0.699	-3.722	-0.981
	DOY:MCLOUD	-0.015	0.006	-0.026	-0.004
	DOY:HCLOUD	0.01	0.007	-0.005	0.024
limpkin					
ψ	intercept	-0.246	0.091	-0.424	-0.068
ε	intercept	-0.107	0.107	-0.317	0.102
p	intercept	-1.105	0.301	-1.694	-0.515
	Lake Hatchineha	2.412	0.407	1.615	3.209
	East Lake Toho	2.63	0.346	1.952	3.308
	Lake Kissimmee	0.265	0.324	-0.371	0.901
	Lake Tohopekaliga	2.399	0.33	1.751	3.046

[a] TEMP = Average temperature (°C) of first and last point sampled each morning. DOY=Julian Date. MCLOUD= Partly-cloudy conditions during point count. HCLOUD=overcast conditions during point count.

Table 4. Model averaged beta estimates for king rail detection probability in the Kissimmee Chain of Lakes, Florida. Detection probability parameter likelihoods (P.L.), weighted parameter estimates (β) and unconditional standard errors (SE) from AIC_c model averaging of robust design occupancy models. Occupancy (ψ) and local extinction (ε) where held constant in all models considered.

Parameter[a]		P.L.	β	SE
ψ	intercept	1	-1.239	0.39
ε	intercept	1	-17.238	1475.8
p	intercept	1	-4.045	1.25
	%VEGCOVER	0.616	3.184	2.008
	p(t-1)	0.257	0.472	0.756
	DOY	0.049	-0.001	0.003
	%EMERGENTVEG	0.007	-0.479	11.445
	NOISE	0.007	-0.001	0.029
	YEAR	0.006	0	0.028

[a] DOY = Julian date, NOISE = subjective scale from 0-5 of noise level at point count. p(t-1) = detection of species at last point visited. %EMERGENTVEG = Proportion of area within 100 m of point that is classified as emergent vegetation. %VEGCOVER = average percent cover by emergent vegetation at 25 plots ($1m^2$) within 100 m of point count location. WIND = average wind speed (Km/h) of first and last point sampled each morning. YEAR = 2009 or 2010,

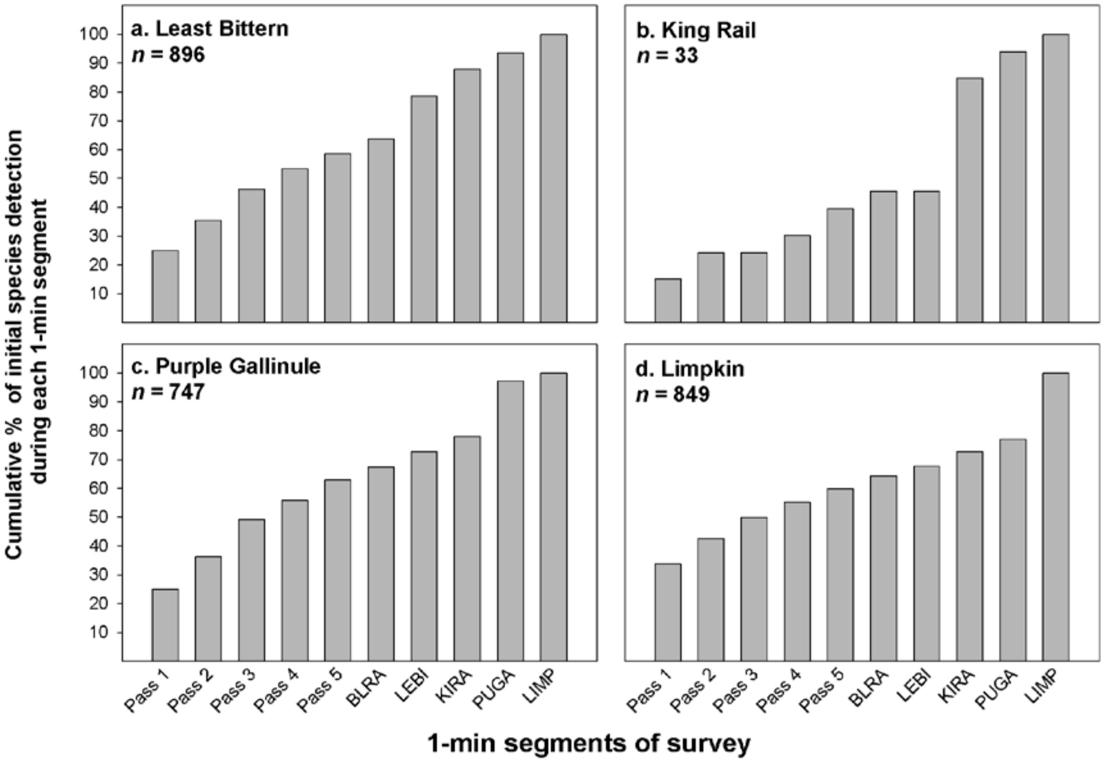

Fig 1. Cumulative percentage of initial detections of secretive marsh bird species on the Kissimmee Chain of Lakes, Florida. Each bar is the cumulative percentage of total initial detection during 10min point counts. Pass1-Pass5 represents 5 1-min segments of an initial passive listening period, and BLRA=black rail, LEBI= least bittern, KIRA=king rail, PUGA=purple gallinule, LIMP=limpkin 1-min call-broadcast segments. Sample size reflects use of 2 simultaneous independent observers.

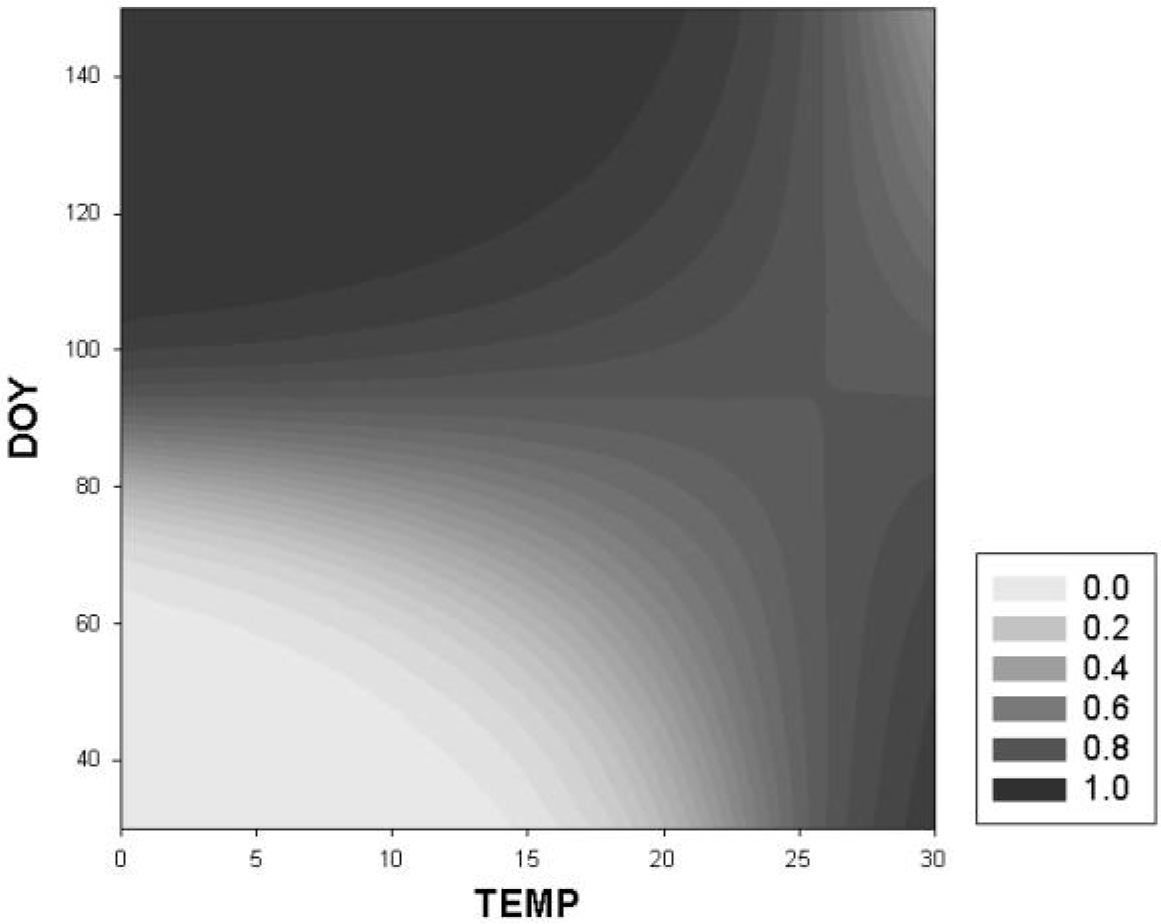

Fig 2. Contour plot of predicted least bittern detection probability on the Kissimmee Chain of Lakes, Florida. Predictions are based on highest AIC_c ranked robust design occupancy model in program MARK. TEMP= average temperature (°C) taken during first and last point count conducted each morning. DOY= Julian date of point count.

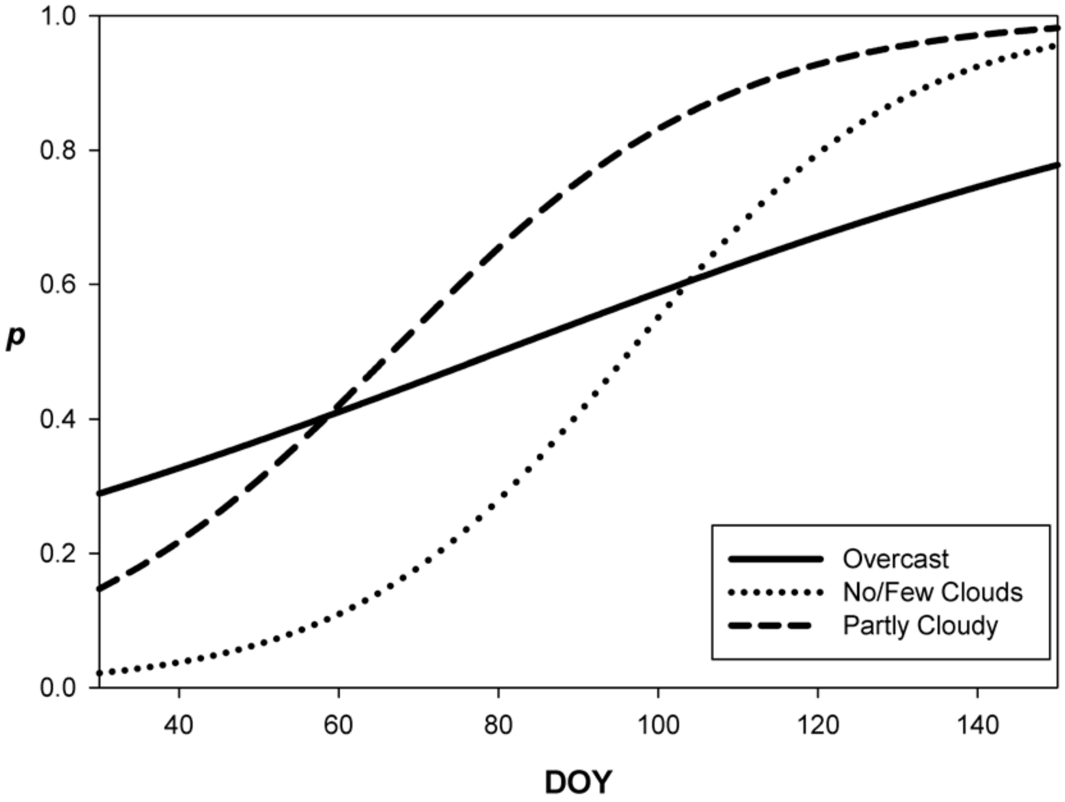

Fig 3.Predicted purple gallinule detection probabilities on the Kissimmee Chain of Lakes, FL. Predictions are based on highest AIC_c ranked robust design occupancy model in program MARK. DOY=Julian date of point count.

CHAPTER III: HABITAT ASSOCIATIONS OF SECRETIVE MARSH BIRDS IN THE KISSIMMEE CHAIN OF LAKES, FLORIDA

ABSTRACT

Loss of marsh habitat has led to population declines of many species of North American marsh birds. However, due to the secretive nature of many of these species there is uncertainty about the population status of these species. Recently developed techniques such as the North American Marsh Bird Monitoring Protocol (NAMBMP) and occupancy analysis can be used to improve both the quality and quantity of information about secretive marsh birds. In 2009 and 2010, we conducted point counts of black rail (*Laterallus jamaicensis*), least bittern (*Ixobrychus exilis*), king rail (*Rallus elegans*), purple gallinule (*Porphyrio martinica*), and limpkin (*Aramus guarauna*) using the NAMBMP in the Kissimmee Chain of Lakes, Florida. We investigated the habitat factors influencing occupancy probability using competing robust design occupancy models in program MARK. Least bittern occupancy had a positive relationship to increasing area covered by vegetation >75cm in height. Purple gallinule occupancy was positively related to proportion of area covered by floating vegetation. Limpkin occupancy was positively related to the proportion of area covered by vegetation cover between 25-75%. King rail occupancy was positively related to proportion of area covered by vegetation cover >75% and to dense floating tussocks. Conserving for diverse assemblages of marsh habitats will support the greatest diversity of secretive marsh birds.

INTRODUCTION

Over 53% of wetlands in the United States were lost from the 1780’s to the mid 1980’s (Dahl 1990). Loss of wetland habitats continues today. For example, an estimated 57,720 ha of freshwater emergent wetlands were lost during the eight year period before 2004 (Dahl 2006). Loss of marsh habitat over the past century has contributed to population declines of many species of secretive marsh birds (i.e., rails and bitterns; Butcher et al. 2007, USFWS 2005, 2008). However, inadequate sampling techniques and low detection rates has created uncertainty about the population status of secretive marsh birds (Cooper 2008, USFWS 2008, Conway 2009, Poole et al. 2009). Traditional techniques to monitor bird populations and assess habitat requirements may not be adequate for marsh birds because these methods do not sample appropriate habitat and do not account for detection probability of secretive marsh birds (Bystrak 1981, Gibbs and Melvin 1993 Conway and Gibbs 2005). Failure to account for detectability can lead to unreliable population estimates and inferences about habitat use (Thompson 2002, Gu and Swihart 2004, Mackenzie et al. 2006).

Information about habitat use of secretive marsh birds is generally lacking (Eddleman et al. 1988, Conway and Gibbs 2005); however, recent studies have begun to close that information gap (e.g., Darrah and Krementz 2009, Rush et al. 2009, Darrah and Krementz 2010, Valente et al. 2011). These studies have used occupancy analysis (Mackenzie et al. 2006) and the recently developed North American Marsh Bird Monitoring protocol (NAMBMP; Conway 2009) to decrease bias due to detectability issues. The NAMBMP was developed to improve information about secretive marsh bird populations (Conway 2009). This protocol uses standardized data collection methods and call-broadcasts of focal species to limit variation in detection probability and increase detection rates. In addition, recently developed techniques such as occupancy analysis (MacKenzie et al. 2006) can be used with data collected using the NAMBMP to account for low and variable detection rates of secretive marsh birds.

Most studies have used single-season occupancy that estimates detection probability by using the pattern of detections and non-detections from multiple site visits. For this reason, these models are sensitive to changes in population status between site visits (Rota et al. 2009). Multi-season or robust design occupancy analysis is an extension of single season occupancy analysis that allows for changes in population status between primary sampling occasions (Mackenzie et al. 2003). In robust design occupancy analysis sampling events are divided into primary periods between which the population is allowed to change, and secondary periods that are temporally close enough to minimize the probability that the population changes (Mackenzie et al. 2003).

In this study we used robust design occupancy analysis of point count data collected using the NAMBMP to investigate habitat characteristics that influence occupancy probabilities of secretive marsh birds in the Kissimmee Chain of Lakes (KCOL), Florida. The natural state of the KCOL has been modified by water control structures that have stabilized water levels and by increased nutrient inputs from agriculture and other developments. These changes have encouraged growth of thick stands of emergent littoral vegetation (Holcomb and Wegener 1971). Current efforts such as spot herbicide treatments and major lake restoration efforts that include water level drawdowns and mechanical removal of vegetation and decaying plant material are used in an effort restore vegetation stands to a more natural state (SFWMD et al. 2008).

However, little is known about the use of littoral vegetation stands by secretive marsh birds such as black rail (*Laterallus jamaicensis*), least bittern (*Ixobrychus exilis*), king rail (*Rallus elegans*), purple gallinule (*Porphyrio martinica*), and limpkin (*Aramus guarauna*) in the KCOL. Use of NAMBMP and robust design occupancy analysis allowed us to gain reliable information about the relationship between the occupancy probability of secretive marsh birds and various small and large scale habitat characteristics that are hypothesized to influence habitat use.

METHODS

Study Area

The KCOL is a series of interconnected shallow lakes in central Florida (Fig 1). The five largest of these lakes are Lake Kissimmee (12,913 ha) Lake Tohopekaliga (7,615 ha), East Lake Tohopekaliga (4,470 ha), Lake Hatchineha (6,629 ha) and Cypress Lake (1,635 ha). These lakes are highly valued for recreation and vary in the degree of shoreline development from undeveloped natural areas to pasture and suburban housing. Littoral stands of vegetation consist primarily of cattail (*Typha spp.)* bulrush (*Scirpus validus)* pickerelweed (*Pontederia cordata*), and spatter-dock (*Nuphar lutea*) but also contain aquatic grasses (*Panicum repens,P. hemitomon, Paspalum repens*), club rush (*Eleocharis cellulosa*), white water lily (*Nymphaea odorata*), American lotus (*Nelumbo lutea*), duck potato (*Sagittaria lancifolia*), knotweed (*Polygonum* spp), alligator weed (*Alternanthera philoxeroides*) and water primrose (*Ludwigia* spp). Some areas of the lakes are characterized by dense floating tussocks comprised of decaying organic matter that are dominated by cattail, pickerelweed, water primrose, wax myrtle (*Myrica* cerifera), willow

(*Salix spp*), buttonbush (*Cephalanthus occidentalis*) arrow arum (*Peltandra virginica*), and wild taro (*Colocasia esculenta*).

Marsh Bird Surveys

We established point count locations along the interface of water and littoral vegetation in Lake Kissimmee (n = 66), Lake Tohopekaliga (n = 46), Cypress Lake (n = 17), East Lake Tohopekaliga (n = 30), and Lake Hatchineha (n = 27). Points were established by selecting a random starting point and subsequent points were placed about 400 m apart to limit double counting of individuals. Point counts (100 m radius) were conducted following the NAMBMP (Conway 2009). This protocol consists of a 5 min passive listening period followed by 1-min periods of 30 seconds of playback and 30 seconds of listening for each focal species. We chose black rail, least bittern , king rail, purple gallinule, and limpkin as focal species because they were thought to historically breed in the area (Bryan 2002, West et al. 2004, Poole et al. 2005, Poole et al. 2009). The order of call-broadcasts was by ascending level of intrusiveness (i.e. black rails are least intrusive followed by least bittern, king rail, purple gallinule and limpkin; Conway 2009). Point counts were conducted 4 times each year at each location in Feb - May 2009 and 2010. Point counts began 30 min before sunrise and were typically completed by 2.5 hr after sunrise (Nadeau et al. 2008) and were not conducted in periods of high wind (>15 km/h) or precipitation. In our sampling design, primary periods were site visits and secondary periods were simultaneous point counts by two independent observers. Observers were trained to identify focal species by sight and sound.

Weather, Habitat and Landscape Characteristics

We recorded air temperature (TEMP, °C) each day as the average of values measured at the first and last point count conducted each day. We recorded cloud cover as clear/few clouds (NCLOUD), partly cloudy (MCLOUD) or overcast (HCLOUD) during each point count. We also sampled vegetation at each point count location. For 141 points we sampled vegetation once in either May - June 2009 or May - June 2010. This was done to limit disturbance to vegetation and resident wildlife. For 45 points that were influenced by local herbicide treatments in fall 2009, we sampled vegetation in both years (May - June 2009 and May-June 2010). We sampled vegetation in the 100 m radius (3.14 ha) patch surrounding each point count location using systematically located plots ($1m^2$; n = 25). Plots were spaced at 25 m intervals along 3 lines running through the point count location. The first line ran perpendicular to the shore and the other lines were placed 45° to either side of the first line. In each plot we recorded vegetation density, height, presence of floating vegetation, and water depth. We first estimated the percentage of each plot that was covered by emergent vegetation. Emergent vegetation within each plot was classified as sparse (<25%), moderate (MODEDENSITY; 25-74%) or dense (HIGHDENSITY ≥75%). Next, we measured the average height of the dominate species of emergent vegetation within each plot and classified it as short (<75cm), medium (PMED; 75-199cm) or tall (PTALL; ≥200cm). Lastly, within each sampling plot we noted whether there was no floating vegetation material, floating leaved vegetation (FLT_V) or a dense floating tussock (FLT_T). We used the proportion of sampling plots that were in each category for vegetation height, cover and the floating vegetation as a measurement of the proportion of the 100 m radius patch surrounding the point count location that was characterized by that vegetation structure. We also recorded the water depth at each sampling plot and used the average water depth over all plots as an estimate of water depth for the patch (H2O).

We also used a digitized littoral vegetation maps (Avinon Inc. 2009, Dewberry 2010), to estimate percentage of area within each 100 m radius patch that was dominated by bulrush (BULRUSH), cattail (CATTAIL), and woody vegetation (SHRUBS) using Fragstats 3.3 (McGarigal and Marks 1995). Digitized littoral vegetation maps were based on 0.30 m resolution aerial photos taken in 2007 (East Lake Tohopekaliga) and 2009 (Lake Kissimmee, Lake Tohopekaliga, Cypress Lake and Hatchineha). To account for changes in vegetation caused by herbicide treatments conducted in fall 2009, we updated littoral vegetation maps in spring 2010 by mapping treated areas with GPS. Percentage of area covered by dead vegetation (DEAD) was quantified and percentage of area covered by CATTAIL, BULLRUSH, and SHRUBS were updated.

We used these digitized vegetation maps to also estimate the degree of interspersion between vegetation and water within the 100 m radius patch of each point count using two measurements. First, we measured the ratio of vegetative cover to water and converted it to a linear relationship. We gave a 50:50 water to vegetation ratio a value of 0, and patches with 100% water or 100% vegetation were given values of 1 (RATIO; Rehm and Baldassarre 2007). A “hemi-marsh” or a marsh with a 50:50 water to cover ratio is typically thought to be ideal for many marsh species (Weller and Spatcher 1965). Habitats that are approach 100% water or 100% vegetation are thus thought to be equally less desirable to many species of marsh birds. Secondly, we measured length of the vegetation to water interface within each patch and calculated edge density (ED, km/3.14 ha). ED will increase as interspersion increases (Rehm and Baldassarre 2007).

Development and recreational boating are common on these lakes and occur at different rates depending on location. We included three variables of human disturbance in the occupancy analysis. Two 10 min fixed radius (2000 m) point counts of boats were conducted each morning after completion of bird surveys to provide an index to boat traffic (BOAT; boats/10 min). Boat point counts were centrally located among the first and second half of the bird point counts conducted each morning. We also measured airboat trails (AIRBOAT; km) within the 100 m radius patch surrounding the point count using aerial photos taken in 2007 or 2009. Finally we used the 2010 Cooperative Land Cover Map (Florida Natural Areas Inventory 2010) and Fragstats 3.3 (McGarigal and Marks 1995) to measure the percentage of landscape within 1000 m of each point count that was classified as developed. We combined low intensity urban, high intensity urban, transportation, communication and utilities land use types into a single classification (LCDEV) for the purpose of our analysis.

Data Analysis

We used robust design occupancy models to estimate the relationships between habitat parameters and occupancy probabilities (Mackenzie et al. 2003). Analysis was performed using RMark (Version 2.0.1, Laake 2010) which is a package for R (Version 2.12.1, R Development Core Team 2010) that constructs models for program MARK (Version 6.0, White and Burnham 1999). Robust design occupancy estimates initial site occupancy (ψ), and local colonization probability (γ), local extinction probability (ε) between primary periods and detection probability (p) for each secondary period. We were primarily interested in ψ, and not the process of ε and γ, so we used an alternate parameterization that estimates p, ψ and ε (Mackenzie et al. 2003). This parameterization estimates p for each secondary period and ψ for each primary period and still allows for changes in ψ between primary periods, but with fewer parameters.

We used a hierarchical modeling framework (e.g., Lebreton et al. 1992), to estimate p by holding ψ and ε constant. We used % VEGCOVER instead of HIGHDENSITY and MODDENSITY in analysis of detection probability. We also included a model with a previous detection variable (p(t-1)) to account for the fact that detections at a point may be related to detections at points previously surveyed (Betts et al. 2008; see Alexander 2011 for complete detection analysis). Models were ranked using models weights based on Akaike's information criterion adjusted for small sample size (AIC_c; Anderson et al. 2000).

Detection models within 2 AIC_c of the highest ranking model were used in model selection for ε models. Eleven different ε models were considered based on *a priori* hypotheses of ε. Models within 2 AIC_c of the best model were used for model selection of ψ models. Preliminary analyses revealed that models containing lake where the point count was conducted (LAKE) were the highest ranked ψ models. Therefore, we included LAKE in all models. The set of models considered for least bittern, purple gallinule, and limpkin consisted of a combination of the highest ranking p, and ε models and a set of 18 univariate and 20 additive ψ models based on *a priori* hypotheses (Appendix B). We found that more complex king rail models often did not converge, so held ε constant and did not include LAKE to limit the number of variables in the models. Models were ranked by AIC_c weight (w_i) and models making up the top 95% of w_i were used to calculate multi-model averaged parameter estimates and parameter likelihoods (Burnham and Anderson 2002). We used unconditional standard errors (Anderson 2008) and 95% confidence intervals to assess beta estimates. We also used odds ratios to interpret effect size.

RESULTS

We completed point counts at each location (n = 186) on 4 occasions in each of 2 years (n = 1488 site visits; n = 2976 point counts). We detected our focal species at least one at 182 sites in 2009, 178 sites in 2010 and 185 sites in both years. Overall, we detected least bittern (0.85), purple gallinule (0.77), and limpkin (0.81) at a greater proportion of points than king rail (0.11; Table 3). We did not detect black rails during point count efforts. Proportion of points with at least one detection varied by survey, lake and species (Tables 3 and 4). In both years the proportion of points with a focal species detection generally increased from the first to the third survey and decreased slightly in the fourth survey (Table 3). Least bitterns were detected at more points during the third survey, purple gallinules were more commonly detected in the fourth survey, and limpkins were more commonly detected during the second survey. King rails were more commonly detected during early surveys each year. Detection of each species varied by lake. Lake Tohopekaliga and Cypress Lake had the greatest proportion of points with least bittern and East Lake Tohopekaliga and Lake Tohopekaliga had the greatest proportion of points with limpkin detections. Lake Kissimmee had the greatest proportion of purple gallinule detections, and Lake Hatchineha had the greatest proportion of points with king rail detections (Table 4).

Detection Probability

The best supported detection models varied by species. Least bittern, purple gallinule and limpkin had a single detection model with > 95% of the AIC_c weight (Table 5, Alexander 2011). The best supported least bittern detection model included relationships with TEMP and DOY and an interaction between DOY and TEMP. The best supported purple gallinule model included MCLOUD, HCLOUD and DOY and interactions between HCLOUD and DOY and MCLOUD and DOY. Limpkin detection probability had the strongest relationship with LAKE. Model selection for king rail included two models within 2 AIC_c of the best detection model. Detection probability was influenced by %VEGCOVER and whether king rails were detected at the previous point (p(t-l)).

Local Extinction Probability

The best supported local extinction models varied by species (Table 5). Two models were within 2 AIC_c of the best model for least bittern and 4 models were within 2 AIC_c of the best model for purple gallinule. The highest ranking model for least bittern included TEMP (0.17 ±0.095 SE), DOY (0.06 ±0.02) and their interaction (-0.003 ± 0.001). The highest ranking model for purple gallinule included YEAR (0.38 ±0.20). The highest ranking model for limpkin included LCDEV (2.62 ± 1.0).

Occupancy Probability

Model selection for least bittern generally favored models that included medium and tall emergent vegetation (Table 6). PMED and PTALL were positively related to occupancy probability of least bitterns (Table 7). Occupancy probability was 1.51 and 1.25 times as likely with every 25% increase in area classified as PTALL and PMED respectively (Fig

2). FLT_V, ED and RATIO had parameter likelihoods > 0.05 however 95% confidence intervals of parameter estimates included 0.

The top occupancy model for purple gallinule included FLT_T, FLT_V and H2O (Table 6). Model averaged parameter estimates indicated that probability of purple gallinule occupancy was 1.42 and 1.19 times as likely with 25% increases in the area of FLT_V and FLT_T (Table 7, Fig 3). Parameter likelihoods of H2O (0.40) and MODDENSITY (0.41) were relatively high but effect size was small (Table 7).

The highest ranking limpkin occupancy model included MODDENSITY (Table 6). MODDENSITY was positively related to limpkin occupancy but the predicted relationship was relatively weak (Table 7). Probability of occupancy was 1.17 times as likely with every 25% increase in MODDENSITY (Fig 4). FLT_V also had a fairly high parameter likelihood (0.38), but the 95% confidence interval of the parameter estimate included 0.

The highest ranking occupancy models for king rail included the variables HIGHDENSITY and FLT_T (Table 6). However, 95% confidence intervals on all model averaged parameter estimates included 0 (Table 7). Model averaged parameter estimated indicated that probability of occupancy by king rails was 2.24 and1.24 times as likely with every 25% increase in HIGHDENSITY and FLT_T, respectively (Table 7, Fig 6).

Parameter likelihoods for LAKE were high, and the effect size differed by species (Table 7). Likelihood of occupancy by least bitterns was greatest on Lake Cypress and lower on East Lake Tohopekaliga, Lake Hatchineha, Lake Kissimmee and East Lake Tohopekaliga (Figure 6). However, purple gallinules and limpkins were less likely to occupy patches on Cypress Lake than other lakes. Occupancy by purple gallinules were more likely on Lake Kissimmee, than on East Lake Tohopekaliga, Lake Hatchineha and Lake Tohopekaliga and Cypress Lake (Figure 6). Occupancy probability was most likely for limpkins on East Lake Tohopekaliga; however the likelihood of occupancy on Lake Hatchineha, Lake Tohopekaliga, and Lake Kissimmee was also greater than Lake Cypress (Figure 6).

DISCUSSION

In our study, we found that least bittern occupancy had the strongest relationship with parameters describing vegetation >75cm in height, but had little support for parameters describing interspersion. Many studies have found that tall emergent vegetation interspersed with open water is characteristic of least bittern habitat. The amount of area dominated by tall vegetation has been shown to have a positive relationship with least bittern habitat use over much of their range, including central Florida (Rodgers and Schwikert 1999, Lor and Malecki 2006, Darrah and Krementz 2010, Valente et al 2011). Even more studies have found a positive relationship with interspersion and least bittern habitat use (e.g. Weller and Spatcher 1965, Gibbs et al. 1991, Bogner and Baldassarre 2002, Rehm and Baldassarre 2007). Littoral vegetation in the KCOL is linear in nature, and distinct zones of vegetation occur with different water depths. In this arrangement, vegetation edges are common for feeding while open areas are available for movement. Therefore, in our study area interspersion may not be a limiting factor.

Occupancy of purple gallinules was most related to floating vegetation in our study. Floating leaved vegetation interspersed with robust emergent vegetation is considered ideal purple gallinule habitat for feeding, movement, nesting and other activities (West and Hess 2002). However, we found little evidence for a relationship with occupancy and any measurement of vegetation density and interspersion. There was some support for a positive relationship with the proportion of area with 25-75% vegetation cover however the effect size was small. Much of the floating leaved vegetation in our study area was spatter-dock, which is a fairly robust floating leaved plant. It often grows 20-40cm above the water. This may provide adequate cover for purple gallinules and may lower the necessity for interspersed tall emergent vegetation such as cattail.

Areas with vegetation cover between 25-75% had the strongest relationship to limpkin occupancy. Few studies have been conducted on habitat use of limpkins. Presence of apple snails, their primary food source, is considered a key component in limpkin distribution (Bryan 2002). Recent studies in South America suggest that patchy emergent vegetation may be an important factor in limpkin habitat selection (Macek et al. 2009). Limpkins will often gather snails from around their home range and bring them back to a few feeding stations in vegetation patches (Bryan 2002). Macek et al. (2009) believed that the foraging habits of limpkins may encourage patchy habitats by centralizing nutrients and encouraging plant growth at feeding stations. Apple snails require emergent vegetation for egg laying and aerial respiration and prefer vegetation that provides some cover, but not so dense as to impede movement (Karunaratne et al. 2006). Our findings of a positive relationship between moderately dense vegetation and limpkin occupancy may reflect limpkins use of habitats that meet this requirement for apple snails. Limpkins are also much larger than the other species in this study and may require moderate density vegetation to provide cover but still facilitate movement.

We found that king rails were not found in many areas of the KCOL. King rails are not listed as threatened in Florida (Cooper 2008), although status and trends are unknown and they are listed as a Species of Greatest Conservation need (FWC 2007). Typically, king rails use shallow water habitats (Meanly 1969) that are not typical of littoral zones. However, much of the shallow marsh habitat in Florida has been lost (Dahl 1990). In our study, presence of high density vegetation and floating tussocks were positively related to king rail occupancy rates. Areas characterized by these features could provide adequate habitat by decreasing the functional water depth for king rails using littoral vegetation stands. Other rail species have been known to use emergent stands with tussocks. For example, Virginia rails (*Rallus limicola*) have been observed feeding in water up to 1 m deep but were able to use these areas due to floating tussocks (Billard 1947). Littoral vegetation stands with dense vegetation and floating tussocks could provide habitat for king rails in areas where shallow marsh vegetation is not abundant. However, this habitat type was not common in the areas we surveyed in the KCOL. It is also possible that our point count locations were not placed in areas appropriate for king rails. We sampled along the vegetation - open water interface where the water is often deepest in the littoral zone. King rails may have not been as common in this portion of littoral vegetation; however, few littoral vegetation stands that we sampled were deep enough to limit sampling the entire stand.

The difference in the likelihood of occupancy between the lakes was also quite large. These lakes are different in size, shape, water temperature, and historical management practices among other things. These differences were not all captured by the habitat variables we measured and some of them were not pertinent to the questions we were asking. For example, limpkins were much more likely to occupy patches on Lake Tohopekaliga and East Lake Tohopekaliga. Snail kites (*Rostrhamus sociabilis*) are also more abundant on these lakes compared to other lakes in the KCOL (Reichert et al. 2011). Both species use apple snails (*Pomacea* spp.) as a primary food source (Sykes et al. 1995, Bryan 2002), and presence of apple snails are thought to be a good predictor of habitat use by limpkins (Bryan 2002). Since snail kites and limpkins are more abundant on these lakes and both are dependent on apple snails it is possible that apple snail populations are more available these lakes leading to greater use by limpkins. We felt that by including LAKE in the models would allow us to better account for unmeasured variation between lakes.

We found a lack of support for parameters describing human disturbance which is contrary to many other studies. Urban and suburban development has been found to have negative effects on habitat use of many species of birds (Hanson et al. 2005, Chace and Walsh 2006). Lake shore development has also been shown to affect use by species such as limpkins, gallinules and other marsh birds. (Hoyer and Canfield 1994, Traut and Hostetler 2004). However, we found little support for this hypothesis except for king rails (though the parameter likelihood was small and the standard error was large). Much of the development around the KCOL is low density housing which may have lower impacts on occupancy rates. Disturbance from watercraft can also be disruptive to birds (Gill 2007). For example, Caroni et al. (2008) found that water birds (including rallidae species) avoided areas of a refuge, both temporally and spatially, where there were greater levels of recreational activity. Airboat traffic on the KCOL is a common form of recreational boating and can be loud and disruptive to wildlife, even more so than other watercraft (Rodgers and Schwikert 2003). Most of our point count locations were in areas with boating traffic yet the amount of airboat trails and boating traffic were poor indicators of occupancy for all species. Other species of water birds have been observed using high traffic areas even though they displayed flushing behavior (Peters and Otis 2006). This may also be the case for these species in the KCOL.

We found few parameters with significant support in our analysis. We considered patch occupancy in our analysis and it may be that differences in habitat association would be more evident if we had considered abundance. Naïve occupancy was fairly high for all species except king rail. However, the number of individuals at each point probably varied much more than presence or absence. There are readily available modeling techniques that account for detectability and abundance (e.g. Royle and Nichols 2003, Royal 2004). However, these models do not account for population changes between site visits. We felt that accounting for population change was important because time between sampling occasions was relatively long. Models that account for abundance, detection probability, and populations changes are being developed but not as widely available (Dial and Madsen 2010). Future analyses accounting for detection probability and abundance may better distinguish between habitat variables.

We found that stands of littoral vegetation with areas of tall vegetation, floating leaved vegetation, moderate to dense vegetation, and floating vegetation have the most potential to support a wide range of secretive marsh bird species. Littoral zones of tall vegetation had the greatest likelihood of occupancy by least bitterns, while purple gallinule occupancy was greatest in stands with floating vegetation and limpkin occupancy was greatest in areas with moderate density vegetation. Overall, king rail occupancy was less likely in the areas we sampled but was most related to dense vegetation and floating tussocks. Management actions that encourage appropriate amounts these types of emergent vegetation structure are most likely to facilitate occupancy by these species.

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Table 1. Descriptions of variables considered for robust design occupancy analysis of least bittern, king rail, purple gallinule, and limpkin in the Kissimmee Chain of Lakes, Florida.

Variable	Description[a]
Study Site	
LAKE	Point count location, Either Lake Hatchineha, East Lake Tohopekaliga, Lake Tohopekaliga, Lake Kissimmee, or Cypress Lake (Intercept)
Human Disturbance	
AIRBOAT	Distance (km) of airboat trails
LCDEV	Percent area within 1000m that is classified as developed
BOAT	Number of boats observed/10min within 2km of point count location
Vegetation	
BULRUSH	Percent area dominated by *Scirpus validus*
CATTAIL	Percent area dominated by *Typha* spp.
DEAD	Percent area that was mapped in 2010 as being dead vegetation
SHRUBS	Percent area as dominated by shrubs
FLT_T	Percent of 25 - $1m^2$ plots with floating tussock
FLT_V	Percent of 25 - $1m^2$ plots with floating vegetation
PTALL	Percent of 25 - $1m^2$ plots with vegetation >200cm tall
PMED	Percent of 25 - $1m^2$ plots with vegetation 75- 199cm tall
HIGHDENSITY	Percent area with vegetation cover ≥75%
MODDENSITY	Percent area with vegetation cover between 25-74%
ED	Density (km/3.14ha) of vegetation to water edge
RATIO	Ratio of vegetation cover to water, 0=50:50 water to water, 1=100% water or vegetation (Rehm and Baldassarre 2007)
Water Depth	
H20	Average water depth (m) at 25 systematic locations

[a] All measurements are within 100 m of point count unless otherwise noted.

Table 2. Mean, standard deviation and range of variables considered for robust design occupancy analysis of least bittern, king rail, purple gallinule, and limpkin in the Kissimmee Chain of Lakes, Florida in 2009 and 2010.

Variable	Mean	SD	Range
Study Site			
LAKE	--	--	--
Human Disturbance			
AIRBOAT	0.34	0.28	0-1.11
LCDEV	0.05	0.08	0-0.37
BOAT	2.33	1.42	0-5.9
Vegetation			
BULRUSH	0.02	0.04	0-0.20
CATTAIL	0.09	0.13	0-0.59
DEAD	0.04	0.09	0-0.45
SHRUBS	0.08	0.13	0-0.59
FLT_T	0.15	0.16	0-0.65
FLT_V	0.18	0.17	0-0.76
PTALL	0.14	0.15	0-0.72
PMED	0.37	0.22	0-0.92
HIGHDENSITY	0.16	0.14	0-0.52
MODDENSITY	0.19	0.14	0-0.72
ED	0.28	0.14	0.02-0.70
RATIO	0.51	0.25	0-1
Water Depth			
H20	0.69	0.24	0.121-1.5

[a] All measurements are within 100 m of point count unless otherwise noted.

Table 3. Proportion of points with at least one detection by year, survey, and species on the Kissimmee Chain of Lakes, Florida.

Year	Survey[a]	n	Least bittern	King rail	Purple gallinule	Limpkin	Total
2009							
	1	186	0.05	0.02	0.1	0.27	0.38
	2	186	0.27	0.03	0.15	0.37	0.61
	3	186	0.51	0.03	0.41	0.32	0.82
	4	186	0.41	0.01	0.47	0.34	0.79
2010							
	1	186	0.05	0.04	0.12	0.29	0.45
	2	186	0.33	0.03	0.13	0.38	0.63
	3	186	0.52	0.02	0.39	0.37	0.78
	4	186	0.42	0.01	0.46	0.28	0.76
Overall		186	0.85	0.11	0.77	0.81	0.99

[a] 2009: Survey 1: 5 Feb- 3 March; Survey 2: 5 March- 30 March; Survey 3: 31 March- 25 April; Survey 4: 4 May- 27 May

2010: Survey 1: 8 Feb-10 March; Survey 2: 13 March- 7 April; Survey 3: 8 April- 1 May; Survey 4: 5 May- 28 May

Table 4. Proportion of points with at least one detection by site, species and overall on the Kissimmee Chain of Lakes, Florida, 2009 and 2010.

Survey site	n	Least bittern	King rail	Purple gallinule	Limpkin	Total
Cypress Lake	17	0.94	0.12	0.59	0.53	1
Lake Hatchineha	27	0.85	0.22	0.52	0.85	0.96
Lake Tohopekaliga	46	0.98	0.11	0.72	0.98	1
Lake Kissimmee	66	0.73	0.09	0.94	0.65	1
East Lake Tohopekaliga	30	0.87	0.07	0.83	1	1

Table 5. Model selection results for detection (p), and local extinction (ε) probability, for least bittern, king rail, purple gallinule, and limpkin in the Kissimmee Chain of Lakes, Florida.

Model	K^a	AIC$_c^b$	w_i^c	Deviance
Detection[d]				
Least bittern				
Ψ (.) ε (.) p (TEMP + DOY + TEMP * DOY)	6	2378.57	1.00	2366.10
King Rail				
Ψ (.) ε (.) p (%VEGCOVER)	4	333.41	0.60	325.41
Ψ (.) ε (.) p (p(t-1))	4	335.15	0.25	327.15
Purple gallinule				
Ψ (.) ε (.) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	8	2180.48	0.96	2163.67
Limpkin				
Ψ (.)ε (.) p (LAKE)	7	2661.62	1.00	2467.00
Local Extinction[e]				
Least bittern				
Ψ (.) ε (TEMP + DOY + TEMP * DOY) p (TEMP + DOY + TEMP * DOY)	9	2416.42	0.31	2398.30
Ψ (.) ε (AIRBOAT) p (TEMP + DOY + TEMP * DOY)	7	2418.38	0.12	2404.30
Purple gallinule				
Ψ (.) ε (YEAR) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	9	2165.21	0.25	2147.09
Ψ (.) ε (DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	9	2165.72	0.19	2147.60
Ψ (.) ε (.) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	8	2166.71	0.12	2150.61
Ψ (.) ε (TEMP) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	9	2167.12	0.10	2148.99
Limpkin				
Ψ (.) ε (LCDEV) p (LAKE)	8	2656.09	0.64	2639.99

[a] K=Number of parameters

[b] AIC$_c$ = Akaike's information criterion corrected for small sample size

[c] w_i = AIC$_c$ model weights

[d] Occupancy (ψ), and local extinction (ε) were held constant for detection models

[e] Models within 2 ΔAIC$_c$ of the top detection probability model were used to select best local extinction models.

YEAR = 2009 or 2010, DOY = Julian day, LAKE = East Lake Tohopekaliga, Lake Tohopekaliga, Cypress Lake, Lake Hatchineha, Lake Kissimmee, HCLOUD = Overcast, MCLOUD = Partly cloudy. TEMP = Average temperature (°C). AIRBOAT = distance (km) of air boats trails within 100 m of point count. LCDEV = Percent of landscape within 1000 m that is developed, %VEGCOVER = average cover of emergent vegetation within 100 m of point count.

Table 6 Robust design occupancy analysis results for least bittern king rail, purple gallinule and limpkin in the Kissimmee Chain of Lakes, Florida. Models within 4 $\Delta \mathrm{AIC}_c$ are listed.

Model[a]	*K*[b]	AICc[c]	$\Delta \mathrm{AIC}_c$[d]	w_i[e]	Deviance
Least bittern					
Ψ (PMED + PTALL) ε (DOY + TEMP + DOY * TEMP) p (DOY + TEMP + DOY * TEMP)	17	2366.74	0.00	0.36	2329.10
Ψ (PTALL + PMED + FLT_V) ε (DOY + TEMP + DOY * TEMP) p (DOY + TEMP + DOY * TEMP)	20	2367.99	1.25	0.19	2322.90
Ψ (PTALL + PMED + RATIO + ED) ε (DOY + TEMP + DOY * TEMP) p (DOY + TEMP + DOY * TEMP)	14	2368.35	1.61	0.16	2337.89
Ψ (PMED + PTALL) ε (DOY + TEMP + DOY * TEMP) p (DOY + TEMP + DOY * TEMP)	17	2369.05	2.31	0.11	2331.40
Ψ (PTALL + PMED + FLT_V) ε (AIRBOAT) p (DOY + TEMP + DOY * TEMP)	15	2370.47	3.73	0.06	2337.64
King rail					
Ψ (HIGHDENSITY) ε (.) p (PREVPT)	5	324.42	0.00	0.42	314.38
Ψ (FLT_T) ε (.) p (PREVPT)	5	326.84	2.42	0.13	316.80
Ψ (DEAD + BOAT + LCDEV + AIRBOAT) ε (.) p (PREVPT)	8	328.29	3.86	0.06	312.19
Purple gallinule					
Ψ (H2O + FLT_T + FLT_V) ε (.) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	15	2073.92	0.00	0.17	2041.09
Ψ (MODDENSITY + FLT_T + FLT_V) ε (.) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	15	2074.67	0.75	0.12	2041.85
Ψ (MODDENSITY + FLT_T + FLT_V) ε (DOY) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	16	2075.36	1.44	0.08	2040.14
Ψ (H2O + FLT_T + FLT_V) ε (DOY) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	16	2075.47	1.55	0.08	2040.25
Ψ (H2O + FLT_T + FLT_V) ε (YEAR) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	16	2075.57	1.66	0.07	2040.35
Ψ (H2O + FLT_T + FLT_V) ε (TEMP) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	16	2076.07	2.15	0.06	2040.85
Ψ (MODDENSITY + FLT_T + FLT_V) ε (YEAR) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	16	2076.12	2.20	0.06	2040.90
Ψ (MODDENSITY + FLT_T + FLT_V) ε (TEMP) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	16	2076.58	2.66	0.04	2041.36
Ψ (ED + PTALL + HIGHDENSITY + MODDENSITY + FLT_V) ε (DOY) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	18	2077.13	3.21	0.03	2037.03

Table 6. (cont.)

Model^a	K^b	AICc^c	ΔAIC$_c^d$	w_i^e	Deviance
Purple gallinule (cont.)					
Ψ (PTALL + PMED + FLT_V) ε (DOY) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	16	2077.29	3.37	0.03	2042.07
Ψ (MODDENSITY + FLT_T + FLT_V) ε (DOY + TEMP + DOY * TEMP) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	17	2077.56	3.64	0.03	2039.92
Ψ (H2O + FLT_T + FLT_V) ε (DOY + TEMP + DOY * TEMP) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	17	2077.78	3.86	0.02	2040.14
Limpkin					
Ψ (MODDENSITY) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	13	2578.12	0.00	0.35	2550.01
Ψ (MODDENSITY + FLT_T + FLT_V) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	15	2579.07	0.94	0.22	2546.24
Ψ (MODDENSITY + HIGHDENSITY + RATIO + ED) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	16	2580.98	2.85	0.08	2545.76
Ψ (CATTAIL + BULRUSH + FLT_V) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	15	2581.89	3.77	0.05	2549.07
Ψ (ED + RATIO + AIRBOAT + HIGHDENSITY + MODDENSITY + DEAD) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	18	2582.09	3.97	0.05	2542.00

[a] AIRBOAT = distance (km) of air boats trails. BOAT = Boats/10 min observed within 2km of point count locations. BULRUSH = % of area dominated by *Scirpus validus*. CATTAIL = % of area dominated by *Typha* spp. DEAD = % of area that was mapped in 2010 as being dead vegetation. DOY = Julian day, LAKE = East Lake Tohopekaliga, Lake Tohopekaliga, Cypress Lake, Lake Hatchineha, Lake Kissimmee, ED = distance (km) of emergent vegetation to water edge, FLT_T = % of area with floating tussock, FLT_V = % of area with floating leaved vegetation, H20 = average depth of water, HCLOUD = Overcast, HIGHDENSITY = % of area with emergent vegetation cover ≥75%, LCDEV = % landscape within 1000 m classified as developed. LCDEV = % landscape within 1000 m classified as developed, MCLOUD = Partly cloudy, MODDENSITY = % of area with emergent vegetation cover between 25-74%. %VEGCOVER = average cover of emergent vegetation within 100 m of point count, PMED = % of area with vegetation >75cm and <200cm in height. PTALL = % of area with vegetation >200cm in height, RATIO = ratio of vegetation cover to water 0 = 50:50 water to water, 1 = 100% water or vegetation (Rehm and Baldassarre 2007), SHRUBS = % of area dominated by shrubs. TEMP = Average temperature (°C). YEAR = 2009 or 2010. All measurements

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Table 6 (cont)

are for the area within 100 m of point count location unless otherwise noted.

[b] K=Number of parameters

[c] $\mathrm{AIC_c}$ = Akaike's information criterion corrected for small sample size

[d] $\Delta\mathrm{AIC_c}$ = difference in $\mathrm{AIC_c}$ relative to the smallest valued

[e] w_i = $\mathrm{AIC_c}$ model weights

Table 7. Model averaged beta estimates (β), unconditional standard errors (SE), and parameter likelihoods (P.L.) for purple gallinule, least bittern, king rail, and limpkins in the Kissimmee Chain of Lakes, Florida. Occupancy parameters listed are from models making up at least 95% of AIC_c model weights for robust design occupancy model selection in program MARK.

Parameter[a]	Least bittern			King rail			Purple Gallinule			Limpkin		
	β	SE	P.L.	β	SE	P.L.	β	SE	P.L.	β	SE	P.L.
Intercept	-0.27	0.04	0.95	-2.06	1.11	0.95	-1.70	0.15	0.95	-1.64	0.33	0.95
Study Site												
East Lake Tohopekaliga	-1.10	0.17	0.95	--	--	--	0.48	0.20	0.95	1.17	0.55	0.95
Lake Hatchineha	-0.60	0.16	0.95	--	--	--	0.35	0.22	0.95	1.08	0.58	0.95
Lake Kissimmee	-0.97	0.13	0.95	--	--	--	1.32	0.11	0.95	0.21	0.56	0.95
Lake Tohopekaliga	-0.21	0.05	0.95	--	--	--	0.56	0.16	0.95	0.94	0.54	0.95
Human Disturbance												
AIRBOAT	--	--	--	-0.30	0.85	0.14	--	--	--	0.02	0.10	0.05
LCDEV	--	--	--	-1.19	3.35	0.13	--	--	--	--	--	--
Vegetation												
BULRUSH	--	--	--	-0.24	2.05	0.03	0.06	0.50	0.02	0.14	0.58	0.07
CATTAIL	--	--	--	0.24	1.17	0.05	0.02	0.15	0.02	-0.03	0.17	0.05
DEAD	--	--	--	-334.24	556.67	0.15	--	--	--	0.00	0.19	0.05
H20	--	--	--	0.06	0.38	0.05	0.07	0.06	0.40	0.00	0.03	0.01
FLT_T	--	--	--	0.99	1.80	0.22	0.68	0.22	0.73	-0.06	0.20	0.22
FLT_V	-0.01	0.03	0.22	-0.21	0.90	0.10	1.41	0.24	0.95	0.31	0.42	0.38
PTALL	1.67	0.15	0.95	--	--	--	0.07	0.22	0.16	0.00	0.13	0.07
PMED	0.90	0.07	0.93	-0.01	0.15	0.00	0.07	0.22	0.08	0.05	0.18	0.08
HIGHDENSITY	0.02	0.15	0.02	3.23	2.81	0.49	0.08	0.25	0.08	0.01	0.17	0.15
MODDENSITY	0.02	0.12	0.02	0.01	0.48	0.04	0.15	0.19	0.41	0.99	0.47	0.72
ED	0.05	0.15	0.11	-0.01	0.29	0.03	0.08	0.24	0.10	-0.03	0.19	0.18
RATIO	0.00	0.01	0.09	-0.04	0.29	0.03	0.00	0.01	0.02	0.09	0.19	0.20

[a] All measurement are of the area within 100 m of point count location unless otherwise noted. LAKE = East Lake Tohopekaliga, Lake Tohopekaliga, Cypress Lake, Lake Hatchineha, Lake Kissimmee, AIRBOAT = Distance (km) of airboat trails within 100 m of point count locations. LCDEV = % landscape

Table 7 (cont.)

within 1000 m classified as developed. BOAT = Boats/10 min observed within 2km of point count locations. BULRUSH = % of area dominated by *Scirpus validus*. CATTAIL = % of area dominated by *Typha* spp. DEAD = % of area that was mapped in 2010 as being dead vegetation. SHRUBS = % of area dominated by shrubs. H20 = average depth of water, FLT_T = % of area with floating tussock, FLT_V = % of area with floating leaved vegetation, PTALL = % of area with vegetation >200cm in height. PMED = % of area with vegetation >75cm and <200cm in height. ED = density (km/3.14ha) of emergent vegetation to water edge, RATIO = ratio of vegetation cover to water 0 = 50:50 water to water, 1 = 100% water or vegetation (Rehm and Baldassarre 2007). HIGHDENSITY = % of area with vegetation cover ≥75%. MODDENSITY = % of area with vegetation cover between 25-74%. YEAR = 2009 or 2010.

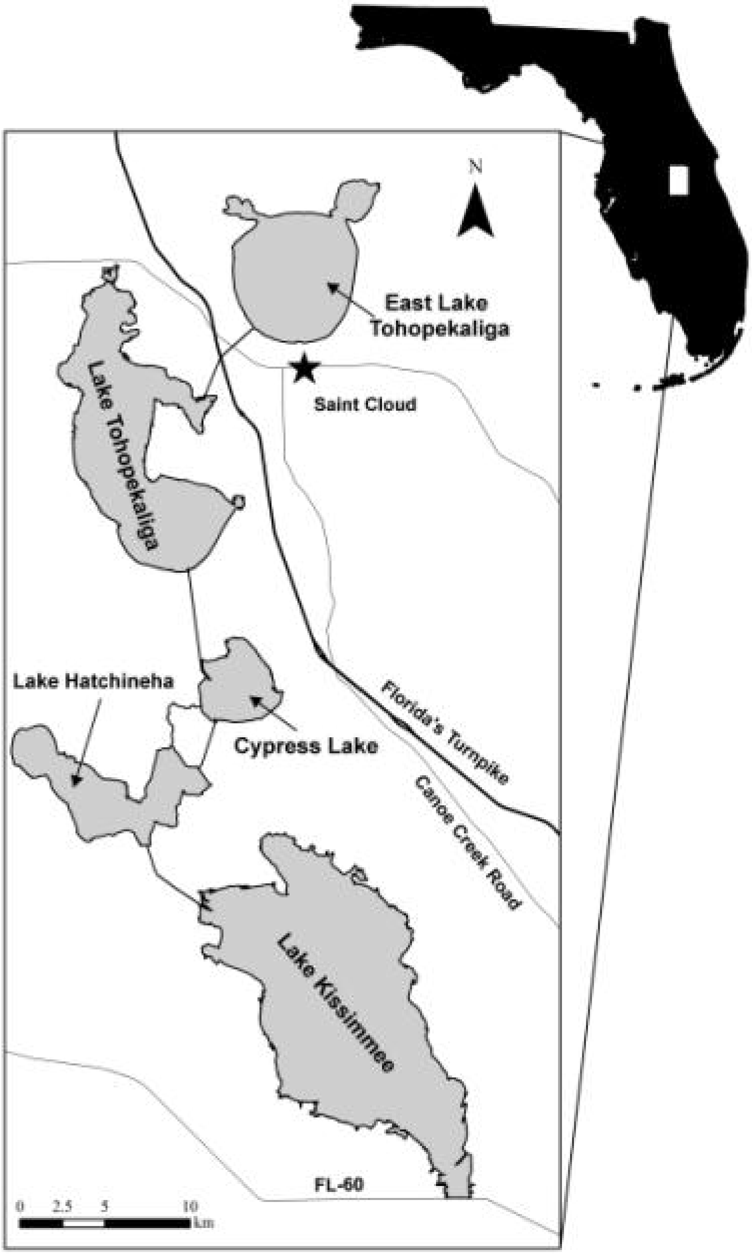

Figure 1.Kissimmee Chain of Lakes, Florida study area.

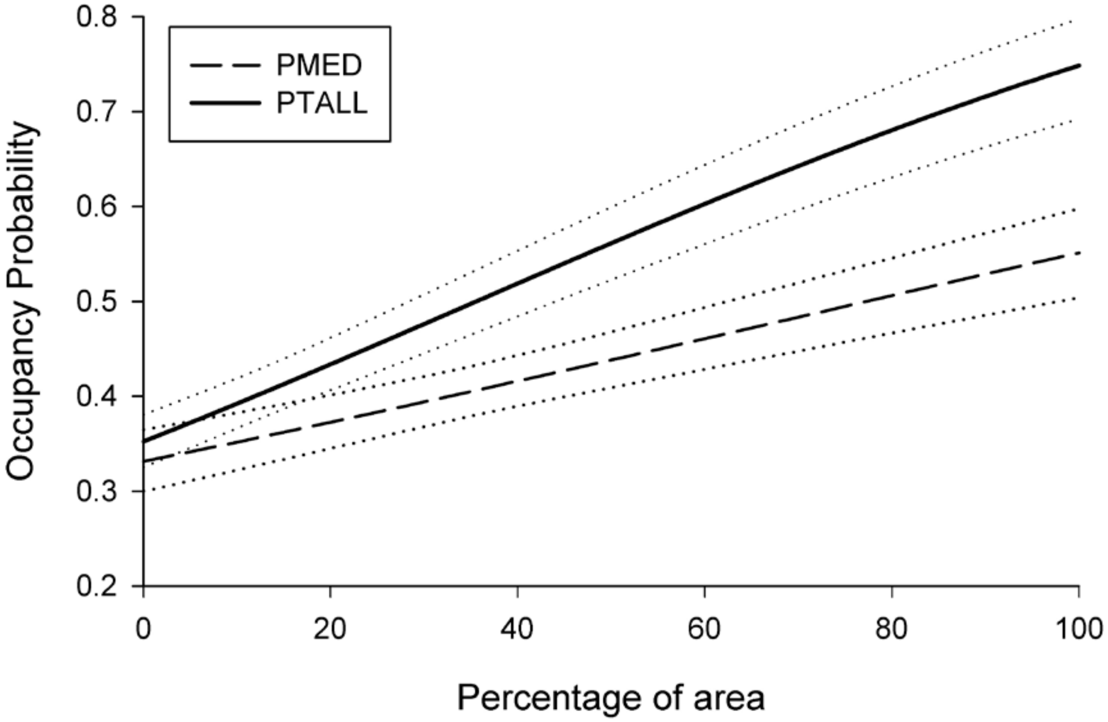

Figure 2. Predicted probability of occupancy (± 95% confidence interval) of least bitterns in relation to emergent vegetation height in the Kissimmee Chain of Lakes, Florida. PTALL = Percent of area within 100 m of point count location with vegetation >200 cm in height. PMED = Percent of area within 100 m of point count location with vegetation between 75-200 cm in height.

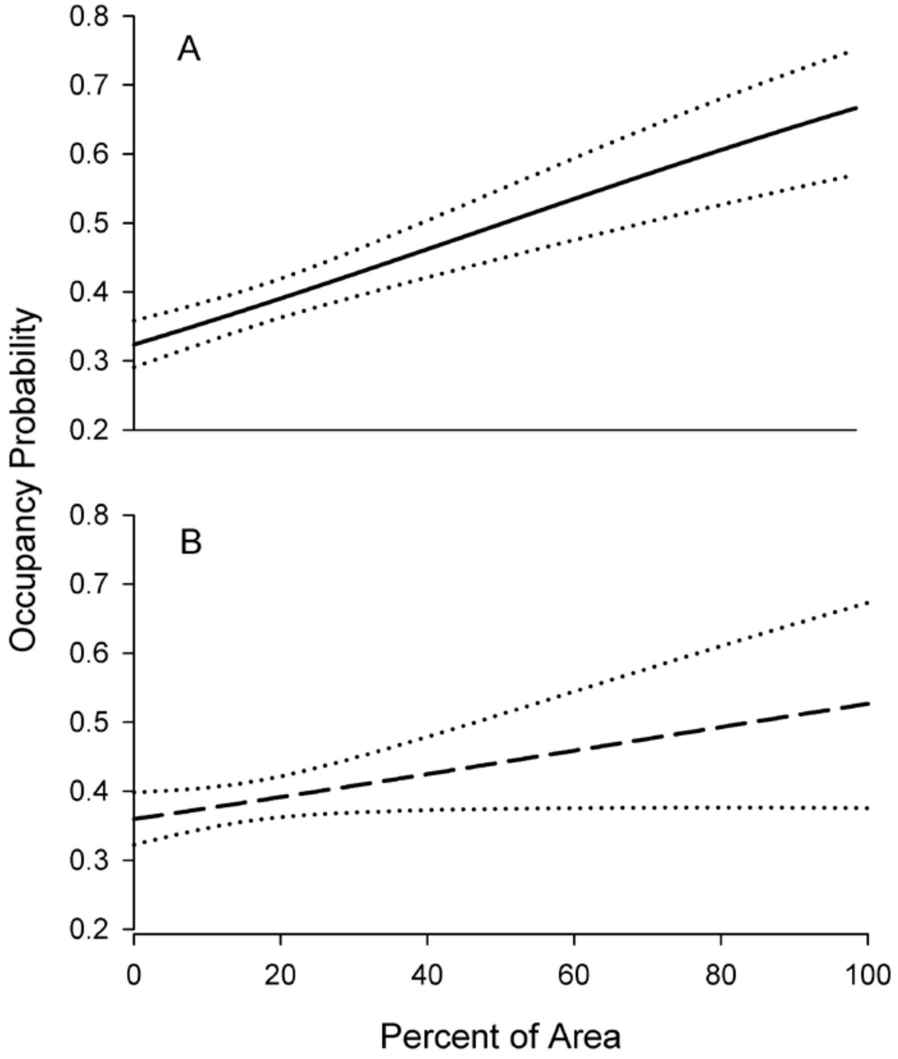

Figure 3. Predicted probability of occupancy (± 95% confidence interval) of purple gallinule in relation to floating vegetation in the Kissimmee Chain of Lakes, Florida. (A) Percent of area within 100 m of point count location with floating leaved vegetation (FLT_V) (B) Percent of area within 100 m of point count location with dense floating tussock (FLT_T).

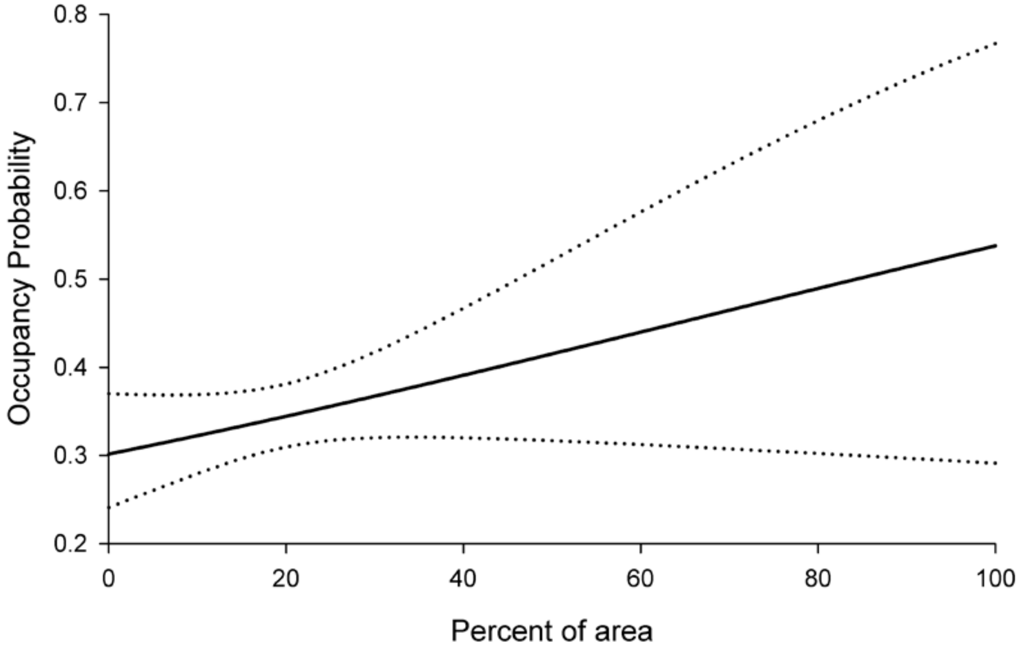

Figure 4. Predicted probability of occupancy (± 95% confidence interval) of limpkins in relation to MODDENSITY of emergent vegetation in the Kissimmee Chain of Lakes, Florida. MODDENSITY = Percent of area within 100 m of point count location with 25-75% emergent vegetation cover.

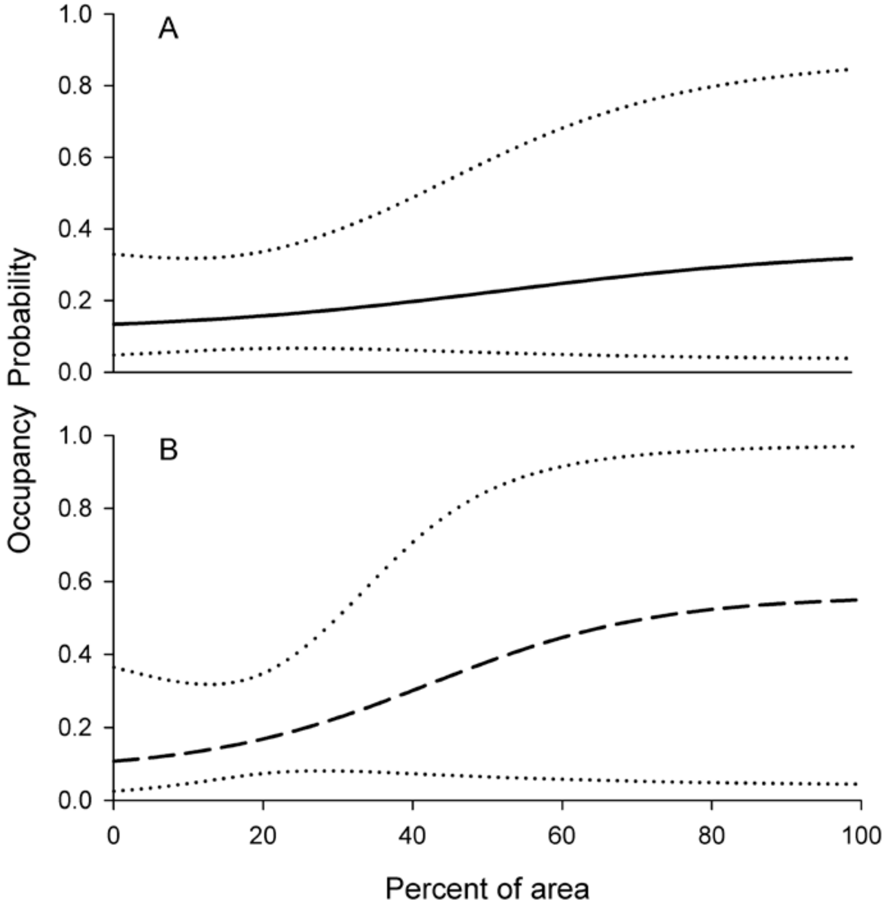

Figure 5. Predicted probability of occupancy (± 95% confidence interval) of king rails in relation to (A) HIGHDENSITY emergent vegetation and (B) FLT_T in the Kissimmee Chain of Lakes, Florida. HIGHDENSITY = Percent of area within 100 m of point count location that has emergent vegetation cover >75%. FLT_T = Percent of area within 100 m of point count location with dense floating tussock.

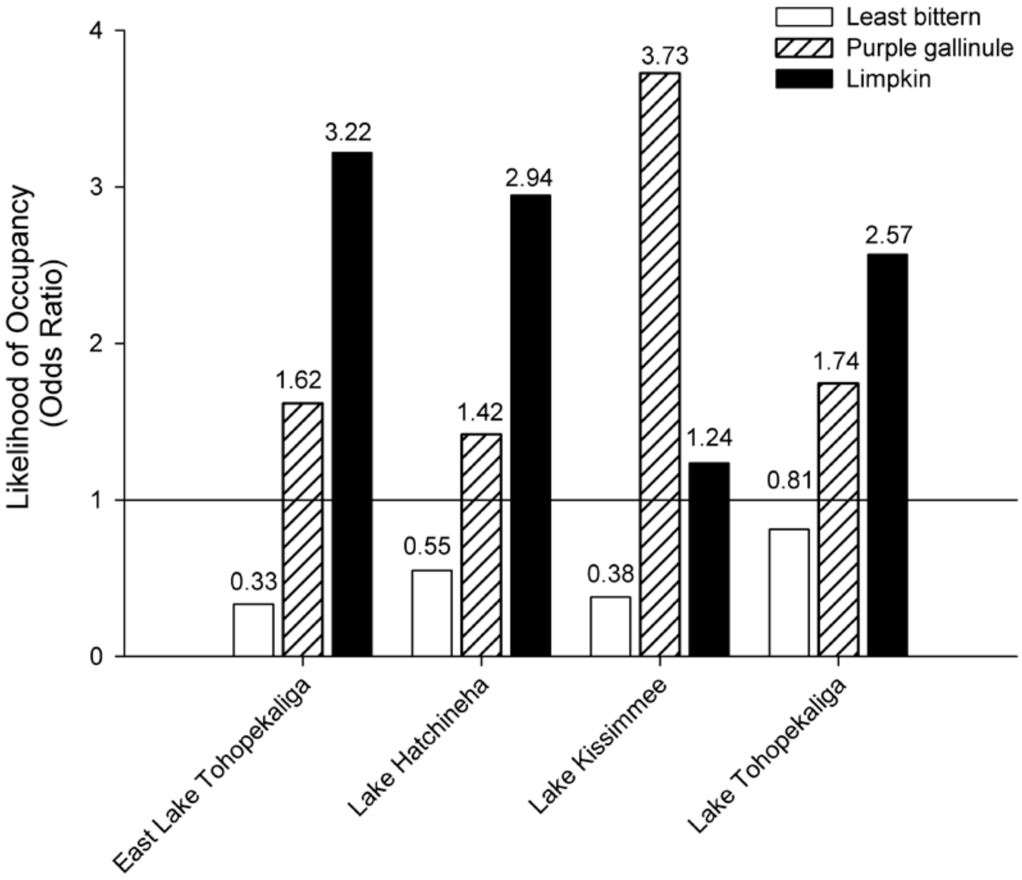

Figure 6. Odds of occupancy as compared to Lake Cypress for least bittern, purple gallinule and limpkin in the Kissimmee Chain of Lakes, Florida. Values given are the model averaged odds of occupancy from robust design occupancy models in program MARK. Horizontal line at 1 indicates the odds of occupancy for Cypress Lake.

Appendix A. AIC_c values for highest ranking models and ΔAIC_c and model weight (w_i) values for all models considered for detection probability of secretive marsh birds in the Kissimmee Chain of Lakes, Florida. Highest ranking detection model for each species is in bold.

Model^a	K	least bittern		king rail		purple gallinule		limpkin	
		w_i	ΔAIC_c	w_i	ΔAIC_c	w_i	ΔAIC_c	w_i	ΔAIC_c
Ψ(.)ε(.) p(.)	3	0.00	131.9	0.02	7.34	0.00	154.29	0.00	53.97
Observer Models									
Ψ(.) ε(.) p(OBS)	8	0.00	138.81	0.00	14.68	0.00	158.58	0.00	55.1
Ψ(.) ε(.) p(CBO)	4	0.00	133.95	--	--	0.00	155.45	0.00	54.49
Ψ(.) ε(.) p(OBS + YEAR)	4	0.00	133.99	--	--	0.00	156.38	0.00	56.06
Ψ(.) ε(.) p(OBS + DOY)	9	0.00	73.58	--	--	0.00	54.55	0.00	46.11
Ψ(.) ε(.) p(OBS + DOY + OBS*DOY)	14	0.00	81.86	--	--	0.00	62.23	0.00	43.81
Ψ(.) ε(.) p(OBS + CBO)	9	0.00	140.81	--	--	0.00	159.6	0.00	54.86
Ψ(.) ε(.) p(OBS + CBO + OBS * CBO)	14	0.00	143.29	--	--	0.00	162.76	0.00	62.28
Prior visit detection models									
Ψ(.) ε(.) p(PRIOROBS)	8	0.00	134.32	--	--	0.00	112.55	0.00	52.05
Ψ(.) ε(.) p(PRIOROBS + OBS)	13	0.00	140.43	--	--	0.00	117.79	0.00	51.01
Ψ(.) ε(.) p(PRIOROBS + OBS + PRIOROBS*OBS)	18	0.00	149.6	--	--	0.00	119.85	0.00	49.84
Detection at previous point									
Ψ(.) ε(.) p(p(t-1))	4	0.00	123.27	0.25	1.74	0.00	154.92	0.00	55.53
Ψ(.) ε(.) p(p(t-1) + OBS)	9	0.00	130.23	--	--	0.00	159.34	0.00	56.86
Ψ(.) ε(.) p(p(t-1) + OBS + p(t-1)*OBS)	14	0.00	141.06	--	--	0.00	166.13	0.00	59.02
Lake models									
Ψ(.) ε(.) p(LAKES)	7	0.00	128.9	0.00	11.78	0.00	133.23	**1.00**	**2661.62**
Vegetation structure									
Ψ(.) ε(.) p(%VEGCOVER)	4	0.00	132.78	**0.61**	**333.41**	0.00	147.97	0.00	55.6
Ψ(.) ε(.) p(%VEGCOVER^2)	5	0.00	134.89	--	--	0.00	150.08	0.00	57.72
Ψ(.) ε(.) p(%EMERGENTVEG)	4	0.00	130.73	0.03	6.36	0.00	153.69	0.00	53.81
Ψ(.) ε(.) p(%EMERGENTVEG^2)	5	0.00	132.84	--	--	0.00	155.69	0.00	55.2
Ψ(.) ε(.) p(%EMERGENTVEG + %VEGCOVER)	5	0.00	131.74	--	--	0.00	146.99	0.00	55.44
Ψ(.) ε(.) p((%EMERGENTVEG + %VEGCOVER %EMERGENTVEG * %VEGCOVER)	6	0.00	133.45	--	--	0.00	149	0.00	57.51
Timing Models									
Ψ(.) ε(.) p(DOY)	4	0.00	72.01	0.05	5.04	0.00	51.51	0.00	45.96
Ψ(.) ε(.) p(DOY^2)	5	0.00	74.12	--	--	0.00	53.63	0.00	48.07

Appendix A (cont.). AIC_c values for highest ranking models and ΔAIC_c and model weight (w_i) values for all models considered for detection probability of secretive marsh birds in the Kissimmee Chain of Lakes, Florida. Highest ranking detection model for each species is in bold.

Model[a]	K	least bittern		king rail		purple gallinule		limpkin	
		w_i	ΔAIC_c	w_i	ΔAIC_c	w_i	ΔAIC_c	w_i	ΔAIC_c
Ψ(.) ε(.) p(TEMP + HCLOUD + MCLOUD + HCLOUD * TEMP + MCLOUD * TEMP)	8	0.00	82.25	--	--	0.00	90.95	0.00	52.41
Ψ(.) ε(.) p(YEAR)	4	0.00	133.73	0.01	9.31	0.00	154.74	0.00	54.3
Ψ(.) ε(.) p(SUNRISE)	4	0.00	133.58	0.01	9.32	0.00	155.38	0.00	51.54
Local Conditions Models									
Ψ(.) ε(.) p(NOISE)	4	0.00	133.6	0.01	8.98	0.00	155.89	0.00	55.32
Ψ(.) ε(.) p(TEMP)	4	0.00	88.75	0.01	9.34	0.00	99.51	0.00	48.07
Ψ(.) ε(.) p(TEMP^2)	5	0.00	90.86	--	--	0.00	101.62	0.00	50.18
Ψ(.) ε(.) p(WIND)	4	0.00	133.79	0.01	9.33	0.00	151.61	0.00	56.05
Ψ(.) ε(.) p(CLOUD)	5	0.00	132.76	0.01	9.36	0.00	145.88	0.00	55.55
Ψ(.) ε(.) p(WIND + DOY + TEMP + CLOUD)	8	0.00	62.62	--	--	0.02	7.8	0.00	51.19
Ψ(.) ε(.) p(TEMP + CLOUD)	6	0.00	92.92	--	--	0.00	88.65	0.00	50.55
Ψ(.) ε(.) p(NOISE + WIND)	5	0.00	135.44	--	--	0.00	153.55	0.00	57.37
Ψ(.) ε(.) p(TEMP + WIND)	5	0.00	90.85	--	--	0.00	101.61	0.00	50.17
Ψ(.) ε(.) p(TEMP + WIND + TEMP*WIND)	6	0.00	89.65	--	--	0.00	99.41	0.00	52
Ψ(.) ε(.) p(DOY + CLOUD)	6	0.00	73	--	--	0.02	8	0.00	47.07
Ψ(.) ε(.) p(DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	8	0.00	64.18	--	--	**0.96**	**2167.42**	0.00	50.59
Ψ(.) ε(.) p(DOY + TEMP)	5	0.00	57.54	--	--	0.00	46.97	0.00	47.38
Ψ(.) ε (.) p(TEMP + DOY + TEMP * DOY)	6	**1.00**	**2419.02**	--	--	0.00	39.91	0.00	36.21

[a] OBS = Observer, 6 different year/observer combinations, CBO = Call-broadcast Equipment Operator, YEAR = 2009 or 2010, DOY = Julian date, PRIOROBS = Observer detected species at point during previous site visit, p(t-1) = detection of species at last point visited, LAKE = East Lake Tohopekaliga, Lake Tohopekaliga, Cypress Lake, Lake Hatchineha, Lake Kissimmee, %VEGCOVER = average percent cover by emergent vegetation of 100 m radius patch, SUNRISE = Hours to sunrise. NOISE= Noise level, scale from 0-5, WIND = wind speed (Km/h), %EMERGENTVEG = Percent of area within 100 m of point that is emergent vegetation, HCLOUD= Overcast, MCLOUD = partly cloudy TEMP = Average morning temperature (°C)

Appendix B. Additive robust design occupancy (**ψ**) models considered for least bittern, king rails, purple gallinules, limpkin in the Kissimmee Chain of Lakes, Florida.

Model[a]
ψ(H2O + FLT_T + FLT_V)ε(*) p(*)
ψ(CATTAIL + HIGHDENSITY + ED + SHRUBS)ε(*) p(*)
ψ(PMED + H2O + DEAD + SHRUBS)ε(*) p(*)
ψ(DEAD + BOAT + LCDEV + AIRBOAT)ε(*) p(*)
ψ(RATIO + ED)ε(*) p(*)
ψ(ED + PTALL + HIGHDENSITY + MODDENSITY + FLT_V)ε(*) p(*)
ψ(+ CATTAIL + BULRUSH)ε(*) p(*)
ψ(FLT_T + SHRUBS + CATTAIL + HIGHDENSITY)ε(*) p(*)
ψ(MODDENSITY + FLT_T + FLT_V)ε(*) p(*)
ψ(PMED + PTALL)ε(*) p(*)
ψ(BOAT + LCDEV + RATIO)ε(*) p(*)
ψ(BOAT + LCDEV + AIRBOAT + RATIO)ε(*) p(*)
ψ(H2O + BULRUSH + RATIO)ε(*) p(*)
ψ(ED + RATIO + AIRBOAT + HIGHDENSITY + MODDENSITY + DEAD)ε(*) p(*)
ψ(PTALL + PMED + RATIO + ED)ε(*) p(*)
ψ(FLT_V + RATIO + ED)ε(*) p(*)
ψ(CATTAIL + BULRUSH + RATIO + ED)ε(*) p(*)
ψ(MODDENSITY + HIGHDENSITY + RATIO + ED)ε(*) p(*)
ψ(PTALL + PMED + FLT_V)ε(*) p(*)
ψ(CATTAIL + BULRUSH + FLT_V)ε(*) p(*)

[a] Detection (*p*) and Local Extinction (ε) models varied by species. PUGA, LEBI and LIMP models also contained categorical variable LAKE. All measurements are for the area within 100 m of point count location unless otherwise noted. LAKE = East Lake Tohopekaliga, Lake Tohopekaliga, Cypress Lake, Lake Hatchineha, Lake Kissimmee, AIRBOAT = Distance (km) of airboat trails within 100 m of point count locations. LCDEV = Percent landscape within 1000 m classified as developed. BOAT = Boats/10 min observed within 2km of point count locations. BULRUSH = Percent of area dominated by *Scirpus validus*. CATTAIL = Percent of area dominated by *Typha* spp. DEAD = Percent of area dominated by dead vegetation. SHRUBS = Percent of area dominated by shrubs. H20 = average depth of water, FLT_T = Percent of area with floating tussock, FLT_V = Percent of area with floating leaved vegetation, PTALL = Percent of area with vegetation >200cm in height. PMED = Percent of area with vegetation >75cm and <200cm in height. ED = distance (km) of emergent vegetation to water edge, RATIO = ratio of vegetation cover to water 0 = 50:50 water to water, 1 = 100% water or vegetation (Rehm and Baldassarre 2007). HIGHDENSITY = Percent of area with emergent vegetation cover ≥75%. MODDENSITY = Percent of area with emergent vegetation cover between 25-74%. YEAR = 2009 or 2010.

Appendix C. Model Selection Results for least bittern, king rail, purple gallinule and limpkin robust design occupancy analysis in the Kissimmee Chain of Lakes, Florida

model	*K*	AIC_c	ΔAICc	*w*	Deviance
Least bittern					
Ψ (PMED + PTALL + KISS + TOHO + HAT + EAST) ε (TEMP + DOY + TEMP * DOY) p (TEMP + DOY + TEMP * DOY)	15	2359.60	0.00	0.55	2326.78
Ψ (PTALL + PMED + FLT_V + KISS + TOHO + HAT + EAST) ε (TEMP + DOY + TEMP * DOY) p (TEMP + DOY + TEMP * DOY)	16	2361.96	2.36	0.17	2326.74
Ψ (PTALL + PMED + RATIO + ED + KISS + TOHO + HAT + EAST) ε (TEMP + DOY + TEMP * DOY) p (TEMP + DOY + TEMP * DOY)	17	2363.19	3.59	0.09	2325.54
Ψ (PMED + PTALL + KISS + TOHO + HAT + EAST) ε (TEMP + DOY + TEMP * DOY) p (TEMP + DOY + TEMP * DOY)	13	2363.29	3.69	0.09	2335.17
Ψ (PTALL + PMED + FLT_V) ε (AIRBOAT) p (TEMP + DOY + TEMP * DOY)	14	2365.63	6.03	0.03	2335.17
Ψ (ED + PTALL + HIGHDENSITY + MODDENSITY + FLT_V + KISS + TOHO + HAT + EAST) ε (AIRBOAT) p (TEMP + DOY + TEMP * DOY)	18	2366.01	6.41	0.02	2325.91
Ψ (PTALL + PMED + RATIO + ED + KISS + TOHO + HAT + EAST) ε (AIRBOAT) p (TEMP + DOY + TEMP * DOY)	15	2366.51	6.91	0.02	2333.68
King rail					
Ψ (HIGHDENSITY) ε (.) p (PREVPT)	5	324.42	0.00	0.42	314.38
Ψ (FLT_T) ε (.) p (PREVPT)	5	326.84	2.42	0.13	316.80
Ψ (DEAD + BOAT + LCDEV + AIRBOAT) ε (.) p (PREVPT)	8	328.29	3.86	0.06	312.19
Ψ (HIGHDENSITY) ε (.) p (.)	4	328.64	4.22	0.05	320.62
Ψ (DEAD + BOAT + LCDEV + AIRBOAT) ε (.) p (VEGCOVER)	8	329.14	4.72	0.04	313.05
Ψ (H2O + FLT_T + FLT_V) ε (.) p (PREVPT)	7	329.36	4.94	0.04	315.28
Ψ (MODDENSITY + FLT_T + FLT_V) ε (.) p (PREVPT)	7	330.21	5.79	0.02	316.14
Ψ (DEAD) ε (.) p (PREVPT)	5	330.57	6.15	0.02	320.53
Ψ (CATTAIL) ε (.) p (PREVPT)	5	330.74	6.32	0.02	320.70
Ψ (FLT_T) ε (.) p (.)	4	330.89	6.46	0.02	322.86
Ψ (DEAD) ε (.) p (VEGCOVER)	5	331.24	6.82	0.01	321.20
Ψ (ED + RATIO + AIRBOAT + HIGHDENSITY + MODDENSITY + DEAD) ε (.) p (.)	9	331.51	7.09	0.01	313.39
Ψ (LCDEV) ε (.) p (VEGCOVER)	5	331.64	7.22	0.01	321.60
Ψ (FLT_T) ε (.) p (VEGCOVER)	5	331.69	7.27	0.01	321.65
Ψ (CATTAIL + BULRUSH) ε (.) p (PREVPT)	6	331.77	7.35	0.01	319.71
Ψ (CATTAIL + BULRUSH + FLT_V) ε (.) p (PREVPT)	7	332.01	7.59	0.01	317.94
Ψ (CATTAIL + BULRUSH + FLT_V) ε (.) p (VEGCOVER)	7	332.02	7.59	0.01	317.94

Appendix C (cont.).

model	*K*	AIC$_c$	ΔAICc	*w*	Deviance
King rail (cont.)					
Ψ (BOAT + LCDEV + AIRBOAT + RATIO) ε (.) p (VEGCOVER)	8	332.19	7.77	0.01	316.10
Ψ (AIRBOAT) ε (.) p (VEGCOVER)	5	332.34	7.92	0.01	322.30
Ψ (DEAD + BOAT + LCDEV + AIRBOAT) ε (.) p (.)	7	332.48	8.05	0.01	318.40
Ψ (FLT_V) ε (.) p (VEGCOVER)	5	332.53	8.11	0.01	322.49
Ψ (RATIO) ε (.) p (VEGCOVER)	5	332.56	8.13	0.01	322.52
Ψ (H2O + FLT_T + FLT_V) ε (.) p (VEGCOVER)	7	332.90	8.48	0.01	318.82
Ψ (H2O + FLT_T + FLT_V) ε (.) p (.)	6	333.15	8.73	0.01	321.10
Ψ (PMED) ε (.) p (VEGCOVER)	5	333.36	8.94	0.00	323.32
Ψ (.) ε (.) p (VEGCOVER)	4	333.44	9.01	0.00	325.41
Purple gallinule					
Ψ (H2O + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (.) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	15	2073.92	0.00	0.17	2041.09
Ψ (MODDENSITY + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (.) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	15	2074.67	0.75	0.12	2041.85
Ψ (MODDENSITY + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2075.36	1.44	0.08	2040.14
Ψ (H2O + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2075.47	1.55	0.08	2040.25
Ψ (H2O + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (YEAR) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2075.57	1.66	0.07	2040.35
Ψ (H2O + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (TEMP) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2076.07	2.15	0.06	2040.85
Ψ (MODDENSITY + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (YEAR) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2076.12	2.20	0.06	2040.90
Ψ (MODDENSITY + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (TEMP) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2076.58	2.66	0.04	2041.36
Ψ (ED + PTALL + HIGHDENSITY + MODDENSITY + FLT_V + KISS + TOHO + HAT + EAST) ε (DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	18	2077.13	3.21	0.03	2037.03
Ψ (PTALL + PMED + FLT_V + KISS + TOHO + HAT + EAST) ε (DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2077.29	3.37	0.03	2042.07

Appendix C (cont.).

model	*K*	AIC$_c$	ΔAICc	*w*	Deviance
Purple gallinule (cont.)					
Ψ (MODDENSITY + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (TEMP + DOY + TEMP * DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	17	2077.56	3.64	0.03	2039.92
Ψ (H2O + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (TEMP + DOY + TEMP * DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	17	2077.78	3.86	0.02	2040.14
Ψ (PTALL + PMED + FLT_V + KISS + TOHO + HAT + EAST) ε (YEAR) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2078.42	4.50	0.02	2043.20
Ψ (ED + PTALL + HIGHDENSITY + MODDENSITY + FLT_V + KISS + TOHO + HAT + EAST) ε (.) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	17	2078.43	4.52	0.02	2040.79
Ψ (PTALL + PMED + FLT_V) ε (TEMP) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2079.27	5.35	0.01	2044.05
Ψ (ED + PTALL + HIGHDENSITY + MODDENSITY + FLT_V + KISS + TOHO + HAT + EAST) ε (YEAR) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	18	2079.43	5.51	0.01	2039.34
Ψ (FLT_V + KISS + TOHO + HAT + EAST) ε (DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	14	2079.61	5.69	0.01	2049.15
Ψ (FLT_V + KISS + TOHO + HAT + EAST) ε (YEAR) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	14	2079.75	5.83	0.01	2049.30
Ψ (CATTAIL + BULRUSH + FLT_V + KISS + TOHO + HAT + EAST) ε (DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2079.81	5.90	0.01	2044.60
Ψ (PTALL + PMED + FLT_V + KISS + TOHO + HAT + EAST) ε (TEMP + DOY + TEMP * DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	17	2079.86	5.94	0.01	2042.21
Ψ (PTALL + PMED + FLT_V + KISS + TOHO + HAT + EAST) ε (.) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	15	2079.86	5.95	0.01	2047.04
Ψ (ED + PTALL + HIGHDENSITY + MODDENSITY + FLT_V + KISS + TOHO + HAT + EAST) ε (TEMP) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	18	2079.92	6.00	0.01	2039.82
Ψ (ED + PTALL + HIGHDENSITY + MODDENSITY + FLT_V + KISS + TOHO + HAT + EAST) ε (TEMP + DOY + TEMP * DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	19	2079.96	6.04	0.01	2037.38
Ψ (FLT_V + RATIO + ED + KISS + TOHO + HAT + EAST) ε (YEAR) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2080.26	6.34	0.01	2045.04
Ψ (FLT_V + RATIO + ED + KISS + TOHO + HAT + EAST) ε (.) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	15	2080.33	6.41	0.01	2047.51

Appendix C (cont.).

model	*K*	AIC$_c$	ΔAICc	*w*	Deviance
Purple gallinule (cont.)					
Ψ (CATTAIL + BULRUSH + FLT_V + KISS + TOHO + HAT + EAST) ε (YEAR) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2080.43	6.51	0.01	2045.21
Ψ (FLT_V + KISS + TOHO + HAT + EAST) ε (TEMP) p (DOY + HCLOUD + MCLOUD + DOY*HCLOUD + DOY*MCLOUD)	14	2081.20	7.28	0.00	2050.74
Ψ (CATTAIL + BULRUSH + FLT_V + KISS + TOHO + HAT + EAST) ε (.) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	15	2081.22	7.30	0.00	2048.39
Ψ (FLT_V + RATIO + ED + KISS + TOHO + HAT + EAST) ε (DOY) p (DOY + HCOULD + MCLOUD + HCLOUD * DOY + MCLOUD * DOY)	16	2081.26	7.34	0.00	2046.04
Limpkin					
Ψ (MODDENSITY + KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	13	2578.12	0.00	0.35	2550.01
Ψ (MODDENSITY + FLT_T + FLT_V + KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	15	2579.07	0.94	0.22	2546.24
Ψ (MODDENSITY + HIGHDENSITY + RATIO + ED + KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	16	2580.98	2.85	0.08	2545.76
Ψ (CATTAIL + BULRUSH + FLT_V + KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	15	2581.89	3.77	0.05	2549.07
Ψ (ED + RATIO + AIRBOAT + HIGHDENSITY + MODDENSITY + DEAD + KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	18	2582.09	3.97	0.05	2542.00
Ψ (FLT_V) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	13	2582.71	4.58	0.04	2554.59
Ψ (PTALL + PMED + FLT_V + KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	15	2583.18	5.05	0.03	2550.35
Ψ (PMED +KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	13	2583.18	5.06	0.03	2555.07
Ψ (RATIO +KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	13	2583.51	5.39	0.02	2555.40
Ψ (FLT_V + RATIO + ED + KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	15	2583.84	5.71	0.02	2551.01
Ψ (ED + PTALL + HIGHDENSITY + MODDENSITY + FLT_V + KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	17	2583.86	5.73	0.02	2546.21
Ψ (H2O + BULRUSH + RATIO +KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	15	2584.54	6.41	0.01	2551.71
Ψ (PTALL + PMED + RATIO + ED + KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	16	2585.05	6.93	0.01	2549.84
Ψ (PMED + PTALL +KISS + TOHO + HAT + EAST) ε (LCDEV) p (KISS + TOHO + EAST + HAT)	14	2585.15	7.03	0.01	2554.70