DISTRIBUTION AND ABUNDANCE OF KING AND CLAPPER RAILS ON THE DELMARVA PENNINSULA

Submitted by:

Tim Freiday and Greg Shriver

Department of Entomology and Wildlife Ecology 250 Townsend Hall, University of Delaware, Newark, Delaware 19716-2160

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ABSTRACT

King (*Rallus elegans*) and Clapper (*Rallus crepitans*) rails co-occur in marshes on the Delmarva Peninsula with King Rails restricted to brackish and fresh-tidal marshes and Clapper Rails occurring in marshes with greater salinity. Our understanding of the distribution and abundance for these two species is limited and King Rail populations have declined across their entire range in recent years. The marshes of the Mid-Atlantic have historically supported King Rails, however, surveys conducted in 2002 found a marked decrease in the number of sites occupied and estimated abundance in the Chesapeake Bay. It was therefore our goal in this project to use standardized protocols to sample historic known King Rail sites and new marshes to evaluate King and Clapper rail populations in the Delmarva Peninsula in 2014 and 2015. We used the same two-stage cluster sampling employed by the Saltmarsh Habitat and Avian Research Program (SHARP; www.tidalmarshbirds.org) to randomly select 40 km^2 hexagons (primary sampling units) in tidal fresh and brackish marshes of the northern Chesapeake and Delaware Bays and randomly located sampling points within each hexagon (secondary sampling units). We surveyed the points within each hexagon using the North American Secretive Marsh Monitoring call-back surveys and added an adaptive sampling component to the design by increasing our sampling effort adjacent to points where King Rails were detected. Our first objectives were to estimate the occupancy and abundance of King and Clapper rails and use a suite of *a priori* hierarchical models to determine which local and landscape features influenced these parameters. Second, we developed adaptive sampling techniques to determine if we could obtain more precise estimates of King Rail abundance in our study area. We found King Rail occupancy was positively related to the amount of *Spartina cynosuroides* at the local scale and King Rail abundance was positively correlated with the amount of emergent marsh and negatively correlated with the amount of forest at the landscape scale. At the local scale, Clapper Rail occupancy was positively related to salinity, *Spartina alterniflora* cover, and *Spartina patens* cover and negatively related to *Typha angustifolia* and *Phragmites australis* cover. At the landscape scale, Clapper Rail occupancy was positively correlated to the amount of emergent vegetation and negatively correlated to the amount of forest and the amount of agriculture within 200 meters of a site. At the local scale, Clapper Rail abundance was positively correlated to the salinity, *Spartina alterniflora*, *Spartina patens* cover and interspersion and negatively correlated with *Typha angustifolia* and *Phragmites australis* cover. At the landscape scale, Clapper Rail abundance was positively correlated to the amount of emergent marsh and negatively correlated to the amount of agriculture and amount of forest within 200 m of a site. The adaptive cluster sampling technique we employed was marginally effective at increasing the precision of our abundance estimates. This technique might be improved by constraining the spatial extent at which it is applied. The adaptive neighborhood transect technique was effective at obtaining high precision estimates of average king rail abundance at occupied sites, which could be useful for increasing the power to detect trends in king rail abundance.

CHAPTER 1:

DISTRIBUTION AND ABUNDANCE OF KING AND CLAPPER RAILS ON THE DELMARVA PENINSULA

INTRODUCTION

Secretive marsh birds occur in freshwater, brackish, and salt marsh habitats of eastern North America. Wetland loss is a primary driver in population declines for some species and despite regulations to limit wetland habitat loss, the extent of coastal wetlands declined by 62,200 acres nationally since 2004 (Eddleman et al. 1988; Greenberg et al. 2006; Wilson et al. 2007; Dahl 2011). The threats to secretive marsh birds are numerous, and many species are declining or their population trends are unknown (Wilson et al. 2007; Darrah and Krementz 2009; Valente et al. 2011; Conway and Gibbs 2011). Despite these population declines, secretive marsh birds are relatively understudied compared to other avian habitats (Johnson et al. 2009). The lack of information on secretive marsh bird status and trends can be attributed to the difficulty of accessing wetland ecosystems and the cryptic and elusive nature of many species inhabiting marshes (Wilson et al. 2007). Traditional bird monitoring efforts such as the Breeding Bird Survey, Christmas Bird Count and the Breeding Bird Atlas do not adequately sample secretive marsh birds, leading to limited information on these species and increasing the need to species or guild specific surveys to better assess status and trends (Conway and Gibbs 2011).

The King Rail (*Rallus elegans*) and Clapper Rail (*Rallus crepitans*) are two Rallid species sympatric in the Delmarva Peninsula. Both species are of conservation concern with limited information related to their distribution and abundance. The King Rail is a large (262 – 425 g), rufescent Rallid associated with fresh and brackish marshes throughout eastern North America (Meanley 1992; Perkins et al. 2009). King Rails are declining throughout much of their range, with negative trends large enough to be detected by the Breeding Bird Survey despite that survey not specifically sampling in marsh habitats (Sauer et al. 2014). On the Atlantic Coast, Clapper Rails are duller in color than their Gulf Coast and West Coast counterparts, displaying plumage with more grays and browns (Hess et al. 2000; Perkins et al. 2009). King Rails can be distinguished from the closely related Clapper Rail by its larger size, richer and brighter colors, and its rufous breast, shoulders, and cheek (Meanley 1992; Perkins et al. 2009). Additionally, Clapper Rails are generally associated with more saline environments, but the ranges of the two species overlap in brackish marshes (Meanley and Wetherbee 1962; Perkins et al. 2009). Unfortunately, when surveying for secretive marsh birds most detections are aural (Conway and Gibbs 2005). As such, King and Clapper rails often must be separated using auditory cues when they are detected. This can be very challenging because there is extensive overlap in the quality of the calls of these two species.

Identification of King and Clapper rails in brackish marsh habitats is confounded by the fact that they are known to hybridize in areas where their ranges overlap (Meanley and Wetherbee 1962; Maley and Brumfield 2013). Hybrids of these two species may exhibit a wide range of plumage and call types that may overlap with both species. Some studies have historically recommended that the two species be combined and considered conspecific, based on a lack of physical differences and the fact that they readily hybridize (Ripley and Olson 1977). More recent studies have maintained that they are two distinct species by using advanced molecular techniques to show differences in their mitochondrial DNA (Maley and Brumfield 2013). The work of Maley and Brumfield (2013) recommends that the *Rallus crepitans* / *elegans* complex should be ordered differently than it has been in the past. They consider King and Clapper rails to be paraphyletic as they have been, but recommend splitting the Clapper Rail complex into different species based more on geographic separation than existing subspecies.

Both King and Clapper rails can acclimate to a range of salinities through extra-renal salt excretion using olfactory bulbs (Conway et al. 1988). Although the rate of excretion is only about 10% of most Larids, the salinity concentrations of the excreted solution is comparable to that of gulls. This allows these two species to adapt to the saline conditions of tidal marshes. Clapper Rails have a larger and more developed olfactory bulb than King Rails which contributes to their success in more coastal environments (Conway et al. 1988). King Rails also have the capability to excrete salt from their olfactory bulbs, so they co-occur with Clapper Rails in brackish marshes.

The Delmarva Peninsula is a land mass in Delaware, Maryland and Virginia that is surrounded by the Atlantic Ocean, Delaware Bay and Chesapeake Bay.

Because of its geographic position, the Delmarva Peninsula contains a large amount of tidal marsh habitat which is important for many waterbird species (Wilson et al. 2007). King and Clapper rails, along with other secretive marsh birds on the Delmarva Peninsula, are threatened by climate change induced sea level rise, habitat loss, habitat shifts, development, anthropogenic chemical inputs, and non-native invasive plants. Sea level rise acts to reduce marsh area, change marsh hydrology, and alter the vegetation composition within a marsh (Field et al. 2016; Beckett et al. 2016; Crosby et al. 2016). Increased periods of inundation caused by rising sea levels decreases plant primary production which leads to a decrease in marsh accretion (Schile et al. 2014). Depending on the rate of sea-level rise, this can cause areas of marsh to turn into mudflats or open water and force high marsh up into what are currently uplands. This is very problematic because in many instances the upland edge of marsh is developed, especially in the Delaware and Chesapeake Bays, which leads to a situation known as a coastal squeeze (Wilson et al. 2007; Torio and Chmura 2013). In the coastal squeeze scenario, tidal marshes have nowhere to migrate on their upland edge because of a barrier such as development, dikes, or hills in their way. The effects of sea level rise may be exacerbated by other processes as well. Ditching and diking of marshes in the Delaware and Chesapeake Bays reduces the amount of sediment available for marsh accretion (Kearney et al. 2002; Wilson et al. 2007). Increased subsidence associated with anthropogenic activities such as oil and groundwater extraction can add to the process of marsh loss and shifting vegetation communities (Wilson et al. 2007).

Development in Delmarva watersheds has led to an increase in impervious surface, which increases erosion due to the higher energy storm water runoff. The level of development and impervious surface has also decreased the amount of upland sediment available for marsh accretion (Wilson et al. 2007; Pappas et al. 2011). Extensive development in the Chesapeake Bay region has had a negative impact on marshbird community integrity (DeLuca et al. 2004). Marsh erosion has also been intensified as a result of increased rainfall and storm surges associated with anthropogenic induced global warming (Michener et al. 1997; Wilson et al. 2007; Schile et al. 2014; Thompson et al. 2014). Increased amounts of impervious surface contributes not only to increased rates of erosion but also adds pollutants and nutrients to wetlands (Najjar et al. 2000; Daly, Bach, and Deletic 2014; Lecce and Pavlowsky 2014).

Pollutants, such as heavy metals and pesticides, deposited in marshes can have detrimental on the health of the organisms inhabiting those marshes (Warner et al. 2010; Ackerman et al. 2012; Casazza et al. 2014). In addition to containing pollutants, storm water runoff often contains elevated levels of nutrients such as phosphorous and nitrogen from fertilizers (Fisher et al. 2006). Additional nutrients are added to the coastal wetlands complex through point sources of pollution such as sewage effluent. The Chesapeake Bay is subject to large amounts of these nutrients which leads to cultural eutrophication (Fisher et al. 2006). This process involves a bloom of phytoplankton as a result of the increased nutrient loading, which in turn leads to increased turbidity of the water. The increased turbidity causes a decrease in submerged aquatic vegetation, and can lead to hypoxic or anoxic environments (Fisher et al. 2006). This in turn can lower food resources available for higher level organisms in the marsh, including secretive marsh birds.

Non-native invasive species specifically, the Common Reed (*Phragmites australis*) is likely the single most detrimental invasive plant species to the marshes of the Mid-Atlantic region (Baiser et al. 2012; Smith 2013). *Phragmites australis* has a strain introduced to the Americas from Europe which is a very aggressive plant invader. *Phragmites australis* is restricted in range by the salinity of the wetlands it inhabits, mainly occurring in oligohaline to mesohaline marshes (0-18 ppt salinity; Lathrop et al. 2003). Despite mainly occurring in fresh and brackish marshes, *Phragmites australis* can spread extensively creating monotypic stands throughout many marshes. These stands of *Phragmites australis* reduces movement through the marsh and limiting the food value to wildlife as *Phragmites australis* does not offer the same habitat cover as native marsh vegetation. Clearly, the loss of the quantity and quality of coastal marsh habitats is a complex process affected by many factors, all of which constitute a threat to the persistence of species which inhabit these vulnerable areas. The loss of coastal wetlands also means a loss of the ecosystem services they provide.

The tidal marsh habitat in the Delmarva peninsula is important for the Mid-Atlantic population of the King Rail (Wilson et al. 2007). Tidal wetlands are some of the last areas where this species still occurs, as it has suffered major declines elsewhere in its range (Glisson et al. 2015). The King Rail population in the Delmarva was noted as declining in the most recent assessment of the marsh birds in the Delmarva Peninsula, which increases the importance of our study (Wilson et al. 2007). Additionally, tidal marsh habitat has declined the most out of any wetland type in the United States from 2004-2009 (Dahl 2011). This loss of tidal wetlands is largely the result of increased coastal erosion caused by stronger and more frequent storms in our warmer climate (Schile et al. 2014; Thompson et al. 2014).

In light of the threats facing secretive marsh birds and the potential importance of the Delmarva Peninsula for King Rails, our objectives were to quantify the occupancy and abundance of King and Clapper rails in the Delmarva and to determine what local and landscape variables best explained the patterns of occupancy and abundance.

METHODS

Survey Area and Point Selection

We selected tidal marshes located on the northern Delmarva Peninsula in the Delaware and Chesapeake Bays. We a used two-stage adaptive cluster sampling to generate secondary sampling units (points) in selected primary sampling units (hexagons) using a generalized random tessellation stratified (GRTS) approach (Johnson et al. 2009, Wiest et al. 2016). We clipped all freshwater and estuarine marshes from the NWI wetlands layer to the hexagons to ensure that points were generated in usable habitat (USFWS 2010, Cowardin et al. 1979). Points were either generated using the GRTS technique, or they were selected from existing points used in historical studies, and were spaced at least 200 m apart. In total, survey data from 498 survey points in the Delmarva Peninsula were used for the analyses (Figure 1.01).

Bird Survey Protocol

We sampled 498 points following the standardized North American Secretive Marshbird Survey Protocol (Conway 2011). This method of sampling employs a five-minute passive period followed by playback of all known breeding secretive marsh birds for a given region. Using playback during point count surveys for secretive marsh birds has been shown to increase the detection rates of secretive marsh birds (Conway and Gibbs 2005; Conway and Nadeau 2010). Detection rate is still imperfect and must be calculated in order to obtain accurate estimates of density (Conway and Gibbs 2011). The marsh bird protocol was designed to allow for multiple methods for estimating detection rates (Conway 2011). We conducted surveys between a half hour before sunrise and 11:00 AM whenever possible. We did not survey during periods of soaking rain or when the sustained winds are above a four on the Beaufort wind scale. All birds using the marsh we identified and categorized into three distance bands: 0-50 m, 50-100 m, and greater than 100 m from the observer.

Because of the challenges in discriminating between King and Clapper rails it is important to clearly define the criteria used during field surveys to discriminate between these two species. Salinity of the marsh habitat has been used to delineate King and Clapper rails and many studies involving King Rails occur in oligohaline and freshwater habitats where only King Rails occur, making identification a much easier task (Meanley 1957; Darrah and Krementz 2009; Valente et al. 2011; Bolenbaugh et al. 2012). The lowest salinity marshes that Clapper Rails are known to breed in are >7,100 ppm at low tide, and >5,600 ppm at high tide (Meanley 1985). More recent assessments of the calls of King and Clapper rails has provided valuable tools for identification (Sibley 2000). The mate attraction call of male King and Clapper Rails is the best way to differentiate between the species. The mate attraction call is given as a series of repeated *kek* notes given by the male and serves as a means to attract a mate or to call a mated female to the calling male (Massey and Zembal 1987; Meanley 1957). The *kek* call averages slower, deeper, richer, and more consistent for King Rails (Sibley, 2000). The fastest portion of this call is useful for identification, with male King Rails delivering *keks* at an average speed of 2 *keks* per second and Clapper Rails delivering *keks* at an average speed of 4 to 5 per second.

For our surveys, rails that never *kek* at a rate faster than 3 per second are classified as King Rails, and birds that *kek* faster than 4 per second are classified as Clapper Rails. Rails that deliver *keks* at a rate of 3-4 per second will be classified as either a King, Clapper, or a hybrid between the two species. We only assigned a definitive species classification to birds that call for at least 60 seconds or are detected visually in areas where both species can be found. By using such strict criteria for classifying these birds to species we will minimize false detections.

Local Covariates

We conducted vegetation surveys at each site using a rapid assessment vegetation survey as per the Saltmarsh Habitat and Avian Research Program (SHARP) protocol (Neckles et al. 2013; www.tidalmarshbirds.org). This protocol calls for a rapid visual assessment of the vegetation community and structure in a circle with a 50-m-radius around the point. Habitat types are broken into cover classes according to the area of the circle they encompass. The species composition of the dominant plant species were estimated as long as they consist of at least 5% of the total area of the circle. All vegetation surveys were completed after June 1st.

We measured salinity at each point using a handheld refractometer to determine the salinity of the nearest water to the point. Salinity measurements were then validated with measurements from monitoring stations in the Chesapeake and Delaware Bays, stations operated by the Chesapeake Bay Monitoring Program and NOAA respectively (CBPWQD 2016, DBOFS 2016). All measurements were averaged in order to obtain a value for the average salinity at each point or monitoring station. Using the data collected by hand and the monitoring stations, a raster was created using inverse distance weighting in ArcGIS spatial analysis to extrapolate the measured values to areas without salinity data (ESRI 2011). The values of the resulting raster were then extrapolated to the survey points themselves as an average salinity value of the point to be used for analysis.

Landscape Covariates

To determine the effect of landscape on the occupancy and abundance of marsh bird species, we used data from the NLCD land cover data to classify the amount of emergent marsh, water, developed land, agriculture, and forest within 200 m of each site (Homer et al. 2015). We used a 200 m buffer and included all land cover pixels within the buffer, because all points are a minimum of 400 m apart, so there is no overlap of land use among sites. Each of these measurements were included as covariates in the model selection analysis (Pickens and King 2012; Glisson et al. 2015; Smith et al. 2016).

Analyses

We developed *a priori* candidate model sets to estimate King and Clapper rail occupancy and abundance and to determine the factors that influence these parameters (Tables 1.01 and 1.02; Burnham and Anderson 2002, Burnham 2016). We used detections within 100 m of the observer to limit the amount bias introduced by the variable detectability of species beyond 100 meters (Buckland et al. 2009; Wiest et al. 2016) to maximize the number of rail detections (Valente et al. 2011), and to maintain independence among points. We used records from the both the passive listening and playback sections of the survey to maximize the amount of data available for analyses.

We used package Unmarked (Fiske and Chandler 2011) in program R (R Development Core Team 2016 to estimate occupancy and abundance for each species. Unmarked uses hierarchical models to quantify detection and state processes separately. We used the '*occu*' function to determine factors affecting occupancy and the '*pcount'* function to determine factors affecting abundance. We developed an *a priori* set of candidate models for detection probability and then used the best detection model to estimate occupancy and abundance (Table 1.01).

We conducted three sets of model selection on King and Clapper rail occupancy and abundance (Table 1.02). First, we compared all covariates (local and landscape scale) together to determine which was the strongest overall influence in an inclusive model selection approach. We then used model selection on the landscape and local scale separately to disentangle the factors that affect occupancy and abundance at each scale. We considered any models within 2 AICc of the top model as competitive (Burnham and Anderson 2002). If the global model was within 2 AICc of the top model, we presumed that all covariates influenced occupancy or abundance and examined the effect of each covariate separately. We provide parameter estimates of the top models and used alpha level = 0.05 to identify significant parameters.

RESULTS

King Rail

We detected King Rails at 34 sites (7.0 % of total). King Rail detection was best explained using Observer and Visit Number covariates which were included in the detection process for all occupancy and abundance models (Table 1.03). The global model was within 2 AICc of the top model (Table 1.04). We therefore examined the beta coefficients of all univariate models contained within the global model (Table 1.05). The percentage of *Spartina cynosuroides* within 50 meters of a point was positively associated with King Rail occupancy (Figure 1.2). Because only one model predicting King Rail occupancy had a statistically significant beta coefficient, we did not perform model selection on the local and landscape scales separately.

We estimated King Rail abundance to be 0.77 ± 0.57 (SE) birds per point across our sampling area. The extent of emergent and forest cover were the two top models for King Rail abundance (Table 1.06). King Rail abundance was positively correlated to the amount of emergent marsh within 200 meters of a point ($\beta = 0.47 \pm 0.18$; Figure 1.3.A). King Rail abundance was negatively correlated with the extent of forest cover within 200 meters of a point ($\beta = -0.52 \pm 0.26$; Figure 1.3.B). King Rail distribution was limited across the survey area (Figure 1.4). The results of the landscape only also indicated that emergent marsh and forest cover were the top models (Table 1.07). The local only model selection indicated that the null model was include in the top models (Table 1.08).

Clapper Rail

We detected Clapper Rail at 229 sites (46.0 % of total). Visit number and observer was the top model for predicting the detection of Clapper Rails within the Delmarva Peninsula (Table 1.09). The global model was the top model for predicting Clapper Rail occupancy (Table 1.10). We used the global model to predict the occupancy while accounting for imperfect detection which yielded an occupancy estimate of 46.43% ± 7.39 (Table 1.11). The global landscape model was the best landscape model (Table 1.12). The global vegetation model was the best local model (Table 1.13).

At the local scale, Clapper Rail occupancy was positively related to salinity (Figure 1.5.A), *Spartina alterniflora* cover (Figure 1.5.B), and *Spartina patens* cover (Figure 1.5.C) and negatively related to *Typha angustifolia* (Figure 1.5.D) and

Phragmites australis cover (Figure 1.5.E). At the landscape scale, Clapper Rail occupancy was positively correlated to the amount of emergent vegetation (Figure 1.5.F) and negatively correlated to the amount of forest (Figure 1.5.G) and the amount of agriculture within 200 meters of a site (Figure 1.5.H). The global model was the top model for predicting Clapper Rail abundance in the inclusive model selection (Table 1.14). The global landscape model was the top model for the landscape level covariates (Table 1.16). The global vegetation model was the top model for the local covariates (Table1.17).

At the local scale, Clapper Rail abundance was positively correlated to the salinity (Figure 1.6.A) *Spartina alterniflora* (Figure 1.6.B), *Spartina patens* cover (Figure 1.6.C) and interspersion (Figure1.6.D) and negatively correlated with *Typha angustifolia* (Figure 1.6.E) and *Phragmites australis* cover (Figure 1.6.F). At the landscape scale, Clapper Rail abundance was positively correlated to the amount of emergent marsh (Figure 1.6.G) and negatively correlated to the amount of agriculture (Figure 1.6.H) and amount of forest within 200 m of a site (Figure 1.6.I). Figure 1.7 shows the distribution of Clapper Rails in our study area based on the abundance estimate for each point.

Discussion

King Rail

King Rail occupancy in the Delmarva was positively correlated with the amount of *Spartina cynosuroides* which has important management implications. King Rails have been shown to have an affinity for this brackish low marsh plant in the Mid-Atlantic (Wilson et al. 2007). *Spartina cynosuroides* is at a competitive disadvantage to two other common wetland plants, *Spartina alterniflora* and *Phragmites australis*. In brackish and fresh marshes, *Phragmites australis* spreads rapidly and can form dense monotypic stands which shade out other plants like *S. cynosuroides* (Lathrop et al. 2003). Rising sea-level is resulting in higher salinities in brackish tidal areas, in addition to increasing the area of low marsh at the expense of high marsh (Scavia et al. 2002; Zedler and Kercher 2004; Clausen and Clausen 2014). The higher salinity in these marshes allows the more salt tolerant *Spartina alterniflora* to outcompete brackish marsh species such as *Spartina cynosuroides* (Chambers et al.; Xia et al. 2015). Therefore, King Rail habitat is being threatened from all sides, and management actions to prevent the loss of brackish marsh plant species diversity to *Phragmites australis* and *Spartina alterniflora* are warranted, such as preservation of large tracts of relatively pristine tidal marshes.

Our results indicated that King Rail abundance was positively correlated to the amount of emergent marsh within 200 meters of a point. These results are consistent with those of a recent study that examined the range wide habitat associations of King Rails (Glisson et al. 2015). Glisson et al. (2015) found that King Rail occupancy across its range was positively correlated to the proportion of land classified by NWI as emergent vegetation surrounding a point. This relationship was significant at all spatial scales we examined (100 - 500 m). Glisson et al. (2015) further found that this relationship generally increased at larger spatial scales, with the strongest model support for the 300 and 350 m scale. Other studies have found similar relationships of

King Rail with emergent marsh. Nesting and brooding King Rails in the upper Mississippi River valley preferred sites dominated by emergent wetland vegetation (Darrah and Krementz 2011). A study of micro-habitat selection of breeding King Rails in the coastal marshes of Louisiana and Texas found that they preferentially selected sites with greater emergent wetland plant species diversity and coverage of water (Pickens and King 2013). This suggests that King Rails prefer nesting sites in the marsh with greater habitat heterogeneity, as well as a large proportion of emergent vegetation.

King Rail abundance in our study area was negatively correlated to the amount of forest within 200 meters of a site. Glisson et al. (2015) found a negative correlation of King Rail occupancy to forested cover, which was significant at smaller spatial scales (100 – 300 m). This correlation was most pronounced at the smallest spatial scales of 50 and 100 m from the point, as these bands held the highest model weight (Glisson et al. 2015). A study of marsh bird habitat associations in the upper Mississippi alluvial valley determined that marsh bird occupancy, including rails, was negatively correlated to the amount of woody vegetation near a site (Bolenbaugh et al. 2011). King Rail occupancy and nesting was negatively correlated to the amount of forest surrounding rice field habitat in Louisiana (Pickens and King 2012). These results suggest that King Rails are less likely to inhabit areas with forest nearby compared to open marsh sites. This is possibly due to an increased presence of mammalian and avian predators in the nearby forested landscape (Pierluissi and King 2008).

Clapper Rail

Many factors we measured had an influence on Clapper Rail occupancy and abundance. When the univariate relationships of the habitat covariates were examined, both occupancy and abundance of Clapper Rail were influenced in similar ways. Clapper Rail occupancy and abundance was positively related to vegetation typically associated with salt marshes, *Spartina alterniflora* and *Spartina patens*. Additionally, Clapper Rail occupancy and abundance was positively correlated with salinity. These associations reflect the Clapper Rails preference for more saline marsh sites (Meanley and Wetherbee 1962; Meanley 1985; Maley and Brumfield 2013). This trend is supported by the fact that occupancy and abundance of Clapper Rails is negatively correlated to *Typha angustifolia* and *Phragmites australis*, two brackish and fresh marsh plant species.

The affinity of Clapper Rails for *Spartina alterniflora* is probably also related to their preference for nesting in taller and more dense vegetation (Valdes et al. 2016). *Spartina alterniflora* grows taller and thicker under low marsh conditions, providing excellent nesting substrate for Clapper Rails (Gaines et al. 2003; Valdes et al. 2016). A study looking into waterbird population trends in the face of sea level rise found that Clapper Rails were positively correlated to *Spartina alterniflora*, as well as brackish and salt marsh (Nuse et al. 2015). The expansion of low-marsh habitat and *Spartina alterniflora* with sea level rise in marshes formerly dominated by brackish vegetation could benefit Clapper Rail populations. This expansion of suitable Clapper Rail habitat will decrease the amount of brackish marsh available for breeding King Rails.

With more Clapper Rails moving into areas formerly occupied by King Rail, the hybridization zone of Clapper Rails and King Rails will likely increase.

The aversion of Clapper Rails to *Phragmites australis* could be a result of the lower horizontal structure owing to a lower stem density than *Spartina alterniflora*. In this way *Phragmites australis* would provide less cover for Clapper Rail nest sites than *Spartina alterniflora*. It could also be that food resources are lower in stands of the invasive *Phragmites australis*, which often forms extensive monocultures (Lathrop et al. 2003). This pattern could also be due to the fact that *Phragmites australis* is less prevalent in salt marsh habitat. The growth of *Phragmites australis* is negatively impacted by high levels of salinity and sulfides, which are features of salt marsh habitat typical of Clapper Rails (Howes et al. 2005; Xia et al. 2015).

Clapper Rail abundance was positively correlated to the level of interspersion within 50 meters of the site. This result has been found for marsh birds in other studies, and indicates a preference for heterogeneous habitat with lots of open water and marsh interface (Darrah and Krementz 2009; Bolenbaugh et al 2011). Areas with heterogeneous habitat likely contain more food resources. Clapper Rail occupancy and abundance was positively correlated with emergent marsh within 200 meters of a point indicating that Clapper Rails have a preference for large expanses of open marsh similar to King Rails. Clapper Rails were less prevalent in areas that had extensive forest cover within 200 meters of a point, which also suggests the requirement of a large area of open marsh habitat.

Clapper Rail occupancy and abundance was negatively correlated to the amount of agriculture within 200 m of a point. Chemical pollution from excess fertilizers and pesticides in the form of runoff from agricultural areas could play a role in this pattern (Goel et al. 2010; Daly et al. 2014). The Chesapeake Bay is affected by a variety of contaminants, which can be derived from sediments contaminated by past land uses (Adams et al. 2008). Erosion of sediments is exacerbated by urbanization, which increases the amount of impervious surface, thereby increasing the energy and amount of water that enters estuaries via runoff (Pappas et al. 2008; Ciavola et al. 2012). This may be part of the reason that the integrity of marshbird communities in the Chesapeake were negatively correlated to the amount of development on the landscape (DeLuca et al. 2004). Organochlorine pesticides such as DDT and DDE have declined over time in this estuary since the ban of their use. However, contemporary compounds like PCBs and modern pesticides (e.g. perfluorinated compounds) have been increasing as a result of continued agricultural and industrial processes. The effects of these compounds are poorly understood and are often manifested in sub-lethal reproductive effects (Rattner and McGowan 2007). It is well known that species living in marshes are often subject to high levels of contaminants related to land use in areas nearby (Cumbee et al. 2008; Warner et al. 2010; Casazza et al. 2014; Ackerman et al. 2012). This could also affect the arthropod prey base of King and Clapper rails in polluted estuaries, reducing local population densities of the two species (Meanley and Wetherbee 1962; Rodríguez et al. 2007; Reichmuth et al. 2009; Rush et al. 2010).

Management Implications and Future Research

It seems apparent that Clapper Rails stand to increase their range as sea level rise and increasing salinity converts brackish marsh into salt marsh. This phenomenon is detrimental to the less common King Rail, which stands to lose overall habitat area and will be subject to increased contact with the sympatric Clapper Rail in the future. King and Clapper rails hybridize when their ranges overlap (Maley and Brumfield 2013). Meanley and Wetherbee (1962) documented cases of such hybridization in the marshes of Delaware when he studied the area in the 1960's, suggesting that this has been occurring in the region for some time (Meanley and Wetherbee 1962). Meanley and Wetherbee (1962) noted that the habitat in the zone of hybridization at Taylor's Gut was more characteristic of typical Clapper Rail habitat, containing roughly 50% *Spartina alterniflora*, 30% *Scirpus robustus*, and 10% each of *Iva frutescens* and *Spartina cynosuroides*. The area of Taylor's Gut where hybridization of the two species occurred was approximately 4.8 km landward from the Delaware Bay.

In an area roughly 1.6 km from the Delaware Bay along the Woodland Beach causeway only Clapper Rails were observed (Meanley and Wetherbee 1962). The habitat here was vegetation was more typical of salt marsh, with vegetation adapted to high salinities and tidal inundation and was comprised of roughly 70% *Spartina alterniflora*, 20% *Spartina robustus,* and 10% *Spartina cynosuroides*. In contrast, the habitat of Fleming's Landing where only King Rails occurred contained a small percentage (15%) of *Spartina alterniflora*, and contained a much larger proportion of high marsh and brackish vegetation with roughly 50% *Spartina patens*, 25% *Scirpus* *olneyi*, 5% *Spartina cynosuroides*, and 5% *Iva frutescens*. Our vegetation surveys in this area revealed that a shift has already occurred, with large amounts of *Spartina alterniflora* and reduced amounts of the high marsh species *Spartina patens* and *Spartina robustus*. The arthropods Red-Jointed Fiddler Crabs (*Uca minax*) and Inconspicuous Macoma (*Macoma balthica*) were abundant in tidal guts of this area and were the main prey items for both rail species (Meanley and Wetherbee 1962). Clapper Rails in the gulf coast feed heavily on fiddler crabs and the size of their home range is negatively correlated to the abundance of these crustaceans (Rush et al. 2010).

Clapper Rails occurred in higher salinity areas with more *Spartina alterniflora*, which is important because the range of this plant species is expanding in the Delaware Bay region due to increasing salinization of the bay (Schuyler et al. 1993). Schuyler et al. (1993) compared the historical ranges of a multitude of submerged aquatic vegetation as well as several brackish and freshwater emergent species to their contemporary ranges. Historical ranges were determined using 19th and 20th century herbarium collections and literature, whereas contemporary ranges were determined by vegetation sampling (Schuyler et al. 1993). Schuyler et al. (1993) found that the southern boundary of many freshwater species of plants such as Annual Wild Rice (*Zizania aquatica*) has shifted northward considerably, as has the northern boundary of wetland species associated with more saline conditions. *Spartina alterniflora*, which was not listed by Tatnall in his 1860 flora of New Castle County, Delaware, now extends along the river from the lower part of the Delaware Estuary to above Wilmington at Bellevue, Delaware, (Schuyler et al. 1993). This increase in salinization of the Delaware Bay is due to increased tidal fluctuations and sea level rise (Hall et al. 2013). Tidal marshes are vulnerable to slight changes in sea level rise as a result of altered hydrology and salinities (Beckett et al. 2016; Crosby et al. 2016).

As changes in sea levels, salinity, and vegetation continue, it is conceivable that there will come a point when no pure King Rails exist in the upper Delmarva. Increasing salinization of the Delaware Bay may also be detrimental to other species of secretive marsh birds breeding in the region. Wild Rice is an excellent food source for wildlife and has been positively correlated with secretive marsh bird occurrence in the Mississippi alluvial valley (Valente et al. 2011). The reduction in the range of Wild Rice in the Delaware Bay due to increasing salinity represents a degradation of the quality of marsh habitat for species such as King Rails and Least Bitterns (*Ixobrychus exilis*) that breed here (Schuyler et al. 1993).

As these changing trends in plant zonation in the region continue along with sea level rise, the suitable King Rail habitat area will decline. Additionally, the range of appropriate habitat for Clapper Rails will migrate further inland. As the range of Clapper Rails increases landward, the zone of hybridization will also shift. The extent of hybridization between King and Clapper rails has not been examined in this region in recent times (Meanley and Wetherbee 1962). We detected far more rails that we were unable to place to either species than we found King Rails in our study. Some of these unknown rails could have been one of the parent species that did not give enough clues to their identification, but others showed traits which were intermediate between the two species. Determining the extent of hybridization in the absence of genetic data is impossible in some cases because of extensive backcrossing resulting in phenotypes very similar to the pure species (Walsh et al. 2015). As such, it is difficult to estimate the true impact of hybridization between King and Clapper rails in tidal marshes using survey data alone. Given the small population size of King Rails we found in the tidal marshes studied, any hybridization constitutes a threat to the persistence of pure King Rails in the form of genetic swamping (Anttila et al. 1998; Cubrinovska et al. 2016; Randall et al. 2016). The true extent of this hybridization in Mid-Atlantic tidal marshes is unknown; further research is required to determine this.

Phragmites australis invasion threatens to lower the diversity and heterogeneity of the oligohaline marshes that the King Rail depends on. Although we found no statistically significant relationship between *Phragmites australis* and King Rail occupancy and abundance, Clapper Rails have been shown to be negatively correlated to *Phragmites australis* presence. It can be inferred that King Rails will not benefit from the increasing prevalence of *Phragmites australis* and the homogenization that *Phragmites australis* monocultures create (Lathrop et al. 2003; Pickens and King 2013).

In light of the extensive threats that face King Rails in the tidal marshes of the Mid-Atlantic, conservation funding should be directed at preserving and managing marshes known to harbor populations of King Rail. Management actions to keep King Rails on the landscape should include the removal of *Phragmites australis* from highly invaded marshes, as well as preventing this plant invader from taking over pristine marshes. Conservation actions aimed at King Rail and other tidal marsh species should include the preservation of upland areas adjacent to tidal marsh habitat. This will allow land managers to minimize the level of disturbance upslope of the marsh which would facilitate the spread of *Phragmites australis* (Packett and Chambers 2006). Preserving upland areas adjacent to tidal marshes has the added benefit of providing areas for the marsh to migrate to, provided the elevation change is not too great and there are no other impediments to marsh transgression (Field et al. 2016; Torio and Chmura 2013).

Purchasing upslope areas that were agricultural and taking them out of production or altering farming practices in areas adjacent to marshes would have additional benefits as well. Limiting the extraction of groundwater could reduce apparent sea level rise by reducing subsidence of the land (Kennish 2001). The Chesapeake Bay is facing an inordinately high rate of marsh loss due to subsidence, as well as climate altered ocean currents increasing the rate of sea-level rise in the area (Kennish 2001; Ezer and Corlett 2012). Increasing the extent of riparian buffers would decrease the level of chemical inputs to the marsh (Dala-Corte et al. 2016; Williams et al. 2016). Both King and Clapper rails showed an affinity for open expanses of marsh free of trees, so preserving large parcels of pristine marsh would be conducive to their population viability. Islands of ghost forest in the middle of otherwise open marsh could be removed to improve habitat quality for King and Clapper Rails.

Our results indicated that there are fewer sites occupied by King and Clapper rails in the eastern shore of Maryland compared to the Delaware Bay. This could be related to the increased impact of pollutants in the Chesapeake Bay, which suffers a high level of contemporary and legacy pollution and is not as well mixed as the Delaware Bay (Sarin and Church 1994; Adams et al. 2008; Paolisso et al. 2015). The arthropod food sources of rails are known to be adversely affected by anthropogenic changes in their environment, such as heavy metal contamination and nutrient loading (Rodríguez et al. 2007; Bartolini et al. 2009; Weis et al. 2011). It is possible that differences in the effective pollutant load of the Chesapeake and Delaware Bays are driving changes in the marsh ecosystem from the bottom trophic level up, resulting in the observed differences in rail occupancy and abundance. Further study is needed to determine the factors driving differences in rail distribution in the Delaware and Chesapeake Bays.

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Table 1.01: Covariates used in detection probability models for King and Clapper rail occupancy and abundance estimation on the Delmarva, 2014-2016.

Model	Parameters
Null	None
Global	Visit Number, Date, Observer, Tide, Time, Temperature, Sky, Wind Speed, and Noise Level
Visit	Visit Number
Day	Survey Date
Observer	Observer
Tide	Tide
Time	Survey Time
Temp	Temperature (F)
Sky	Sky
Wind	Wind Speed
Visit + Observer	Visit Number and Observer
Noise	Noise Level

Table 1.02: Models to determine the factors that influence occupancy and abundance for King and Clapper rails on the Delmarva, 2014-2015.

Scale	Model	Parameters
Local	*S. alterniflora*	% *Spartina. alterniflora*
	S. patens	% *Spartina patens*
	S. cynosuroides	% *Spartina cynosuroides*
	T. angustifolia	% *Typha. angustifolia*
	P. virginica	% *P. virginica*
	P. australis	% *P. australis*
	I. frutescens	% *Iva frutescens*
	Vegetation	*S. alterniflora, S. patens, S. cynosuroides, T. angustifolia, P. virginica, P. australis, and I. frutescens*
	Interspersion	Cover class factor of the amount of pools, pannes and creeks w/in 50 m of the point
Landscape	Agriculture	Agricultural land cover within 200 m
	Developed	Developed land cover within 200 m
	Emergent	Emergent marsh cover within 200 m
	Forest	Forest cover within 200 m
	Landscape	Agriculture+Developed+Emergent+Forest cover within 200 m
	Global	Year+Salinity+Salinity^2+*S. alterniflora+S. patens+S. cynosuroides+T. angustifolia+P. virginica+P. australis+I. frutescens*+Interspersion+Upland+Emergent, Developed+Agriculture+Water
	Year	2014, 2015
	Null	(.)

Table 1.03: Detection Model Selection - King Rail Abundance in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Visit + Observer	11	456.57	0	0.77
Observer	10	458.96	2.39	0.23
Temperature	3	468.93	12.36	0.02
Visit Number	3	471.80	15.23	0.03
Wind	3	472.96	16.39	0.01
Time	3	472.97	16.4	0.01
Julian Day	3	473.82	17.25	0.00
Sky	3	473.92	17.35	0.00
Noise	3	475.22	18.65	0.00
Tide	7	482.87	26.3	0.00

Table 1.04: Occupancy Model Selection for King Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
S. cynosuroides	12	366.73	0	0.27
Emergent	12	367.20	0.47	0.22
Forest	12	368.16	1.43	0.13
Global	26	368.31	1.58	0.12
Agriculture	12	370.07	3.33	0.05
Null	11	371.31	4.57	0.03
I. frutescens	12	371.58	4.84	0.02
P. virginica	12	372.39	5.65	0.02
P. australis	12	372.41	5.68	0.02
Landscape	16	372.62	5.89	0.02
S. alterniflora	12	372.80	6.06	0.01
Year	12	372.80	6.07	0.01
S. patens	12	372.81	6.08	0.01
Interspersion	12	372.82	6.09	0.01
T. angustifolia	12	372.92	6.18	0.01
Water	12	372.94	6.21	0.01
Developed	12	373.11	6.37	0.01
Salinity	12	373.30	6.57	0.01
Vegetation	18	380.21	13.48	0.00

Table 1.05: Factors Affecting King Rail Occupancy in the Delmarva Peninsula, 2014-2015

Parameter	Estimate	SE	Z-Score	P(>|z|)
2014	-0.784	0.728	-1.077	0.281
2015	0.774	1.300	0.595	0.552
Salinity	0.0172	0.273	0.063	0.950
S. alterniflora	0.234	0.412	0.567	0.571
S. patens	-0.19	0.273	-0.697	0.486
S. cynosuroides	3.087	1.520	2.028	0.043
T. angustifolia	0.0951	0.162	0.588	0.556
P. virginica	2.24	26.39	0.085	0.932
P. australis	-0.227	0.246	-0.920	0.357
I. frutescens	-0.42	0.348	-1.207	0.227
Interspersion	0.119	0.177	0.673	0.501
Emergent	0.792	0.657	1.206	0.228
Developed	-0.108	0.246	-0.440	0.660
Agriculture	-0.606	0.405	-1.499	0.134
Water	-0.172	0.294	-0.586	0.558
Forest	-0.724	0.391	-1.850	0.064

Table 1.06: Abundance Model Selection for King Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Emergent	12	450.92	0.00	0.50
Forest	12	452.83	1.91	0.19
Agriculture	12	455.03	4.12	0.06
Null	11	456.57	5.65	0.03
Landscape	16	456.70	5.78	0.03
I. frutescens	12	456.84	5.93	0.03
Developed	12	457.42	6.51	0.02
P. australis	12	457.50	6.58	0.02
S. cynosuroides	12	457.51	6.59	0.02
S. alterniflora	12	457.54	6.62	0.02
Year	12	457.84	6.93	0.02
Salinity	12	458.06	7.15	0.01
S. patens	12	458.09	7.18	0.01
T. angustifolia	12	458.29	7.37	0.01
Water	12	458.45	7.53	0.01
Interspersion	12	458.46	7.54	0.01
P. virginica	12	458.55	7.64	0.01
Vegetation	18	466.33	15.41	0.00
Global	26	472.50	21.58	0.00

Table 1.07: Landscape Abundance Model Selection for King Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Emergent	12	450.92	0.00	0.57
Forest	12	452.83	1.91	0.22
Agriculture	12	455.03	4.12	0.07
Null	11	456.57	5.65	0.03
Landscape	16	456.7	5.78	0.03
Developed	12	457.42	6.51	0.02
Year	12	457.84	6.93	0.02
Salinity	12	458.06	7.15	0.02
Water	12	458.45	7.53	0.01

Table 1.08: Local Abundance Model Selection for King Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Null	11	456.57	0.00	0.16
I. frutescens	12	456.84	0.27	0.14
P. australis	12	457.50	0.93	0.10
S. cynosuroides	12	457.51	0.94	0.10
S. alterniflora	12	457.54	0.97	0.10
Year	12	457.84	1.27	0.08
Salinity	12	458.06	1.49	0.07
S. patens	12	458.09	1.53	0.07
T. angustifolia	12	458.29	1.72	0.07
Interspersion	12	458.46	1.89	0.06
P. virginica	12	458.55	1.98	0.06
Vegetation	18	466.33	9.76	0.00

Table 1.09: Detection Model Selection for Clapper Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Visit + Observer	11	3319.75	0.00	1.00
Observer	10	3373.41	53.66	0.00
Temperature	3	3533.66	213.9	0.00
Visit Number	3	3539.61	219.86	0.00
Julian Day	3	3541.18	221.43	0.00
Time	3	3557.42	237.67	0.00
Sky	3	3584.28	264.53	0.00
Tide	7	3592.05	272.30	0.00
Noise	3	3597.98	278.23	0.00
Wind	3	3602.53	282.78	0.00

Table 1.10: Occupancy Model Selection for Clapper Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Global	26	1572.66	0.00	1.00
Landscape	16	1624.00	51.34	0.00
Emergent	12	1651.16	78.49	0.00
Forest	12	1659.78	87.11	0.00
Vegetation	18	1665.56	92.90	0.00
P. australis	12	1692.30	119.64	0.00
Salinity	12	1697.46	124.80	0.00
S. alterniflora	12	1702.18	129.52	0.00
Agriculture	12	1706.78	134.12	0.00
T. angustifolia	12	1717.85	145.18	0.00
Year	12	1720.04	147.38	0.00
S. patens	12	1727.67	155.00	0.00
P. virginica	12	1730.47	157.81	0.00
S. cynosuroides	12	1731.88	159.21	0.00
Interspersion	12	1732.42	159.75	0.00
Developed	12	1732.89	160.23	0.00
Null	11	1733.11	160.44	0.00
Water	12	1734.02	161.35	0.00
I. frutescens	12	1734.40	161.74	0.00

Table 1.11: Factors Affecting Clapper Rail Occupancy in the Delmarva Peninsula, 2014-15

Parameter	Estimate	SE	Z-Score	P(>|z|)
2014	0.257	0.122	2.110	0.035
2015	-1.245	0.276	-4.510	<0.001
Salinity	0.097	0.018	5.350	<0.001
S. alterniflora	3.353	0.794	4.220	<0.001
S. patens	2.394	0.953	2.511	0.012
S. cynosuroides	2.117	1.365	1.551	0.121
T. angustifolia	-11.450	3.681	-3.110	<0.001
P. virginica	-115.634	221.533	-0.522	0.602
P. australis	-4.456	0.755	-5.910	<0.001
I. frutescens	-1.039	1.222	-0.850	0.395
Interspersion	0.119	0.073	1.616	0.106
Emergent	1.116	0.150	7.420	<0.001
Developed	-0.158	0.105	-1.500	0.134
Agriculture	-0.732	0.163	-4.480	<0.001
Water	-0.107	0.102	-1.050	0.293
Forest	-1.300	0.204	-6.392	<0.001

Table 1.12: Landscape Occupancy Model Selection for Clapper Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Landscape	16	1624.00	0.00	1.00
Emergent	12	1651.16	27.15	0.00
Forest	12	1659.78	35.77	0.00
Salinity	12	1697.46	73.46	0.00
Agriculture	12	1706.78	82.78	0.00
Year	12	1720.04	96.04	0.00
Developed	12	1732.89	108.89	0.00
Null	11	1733.11	109.10	0.00
Water	12	1734.02	110.01	0.00

Table 1.13: Local Occupancy Model Selection for Clapper Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Vegetation	18	1665.56	0.00	1.00
P. australis	12	1692.30	26.74	0.00
Salinity	12	1697.46	31.90	0.00
S. alterniflora	12	1702.18	36.62	0.00
T. angustifolia	12	1717.85	52.29	0.00
Year	12	1720.04	54.48	0.00
S. patens	12	1727.67	62.11	0.00
P. virginica	12	1730.47	64.91	0.00
S. cynosuroides	12	1731.88	66.32	0.00
Interspersion	12	1732.42	66.86	0.00
Null	11	1733.11	67.55	0.00
I. frutescens	12	1734.40	68.84	0.00

Table 1.14: Abundance Model Selection for Clapper Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Global	26	2966.05	0.00	1.00
Landscape	16	3068.44	102.40	0.00
Vegetation	18	3139.43	173.38	0.00
Forest	12	3154.36	188.31	0.00
Emergent	12	3166.36	200.32	0.00
P. australis	12	3195.80	229.76	0.00
S. alterniflora	12	3243.62	277.57	0.00
Agriculture	12	3245.50	279.45	0.00
Salinity	12	3278.22	312.18	0.00
T. angustifolia	12	3296.55	330.50	0.00
Year	12	3301.72	335.67	0.00
Interspersion	12	3307.97	341.93	0.00
S. cynosuroides	12	3313.10	347.05	0.00
P. virginica	12	3313.48	347.43	0.00
I. frutescens	12	3317.35	351.31	0.00
S.patens	12	3317.87	351.82	0.00
Developed	12	3318.78	352.74	0.00
Null	11	3319.75	353.71	0.00
Water	12	3319.96	353.91	0.00

Table 1.15: Factors Affecting Clapper Rail Abundance in the Delmarva Peninsula, 2014-15

Parameter	Estimate	SE	Z-Score	P(>|z|)
2014	0.713	0.088	8.13	<0.001
2015	-0.853	0.189	-4.51	<0.001
Salinity	0.044	0.006	7.442	<0.001
S. alterniflora	1.491	0.158	9.42	<0.001
S. patens	0.747	0.313	2.39	0.002
S. cynosuroides	0.423	0.466	0.908	0.030
T. angustifolia	-24.920	7.350	-3.39	<0.001
P. virginica	-105.400	243.796	-0.432	0.067
P. australis	-4.460	0.480	-9.29	<0.001
I. frutescens	-1.082	0.576	-1.88	0.006
Interspersion	0.079	0.030	2.69	<0.001
Emergent	0.576	0.055	10.49	<0.001
Developed	-0.044	0.047	-0.949	0.343
Agriculture	-0.596	0.110	-5.4	<0.001
Water	-0.098	0.048	-2.06	0.039
Forest	-0.982	0.118	-8.31	<0.001

Table 1.16: Landscape Abundance Model Selection for Clapper Rail in Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Landscape	16	3068.44	0.00	1.00
Forest	12	3154.36	85.92	0.00
Emergent	12	3166.36	97.92	0.00
Agriculture	12	3245.50	177.05	0.00
Salinity	12	3278.22	209.78	0.00
Year	12	3301.72	233.27	0.00
Developed	12	3318.78	250.34	0.00
Null	11	3319.75	251.31	0.00
Water	12	3319.96	251.51	0.00

Table 1.17: Local Abundance Model Selection for Clapper Rail in the Delmarva Peninsula, 2014-15

Model	nPars	AIC	Δ AIC	AICwt
Vegetation	18	3139.43	0.00	1.00
P. australis	12	3195.80	56.37	0.00
S. alterniflora	12	3243.62	104.19	0.00
Salinity	12	3278.22	138.79	0.00
T. angustifolia	12	3296.55	157.12	0.00
Year	12	3301.72	162.29	0.00
Interspersion	12	3307.97	168.54	0.00
S. cynosuroides	12	3313.10	173.67	0.00
P. virginica	12	3313.48	174.05	0.00
I. frutescens	12	3317.35	177.92	0.00
S. patens	12	3317.87	178.44	0.00
Null	11	3319.75	180.32	0.00

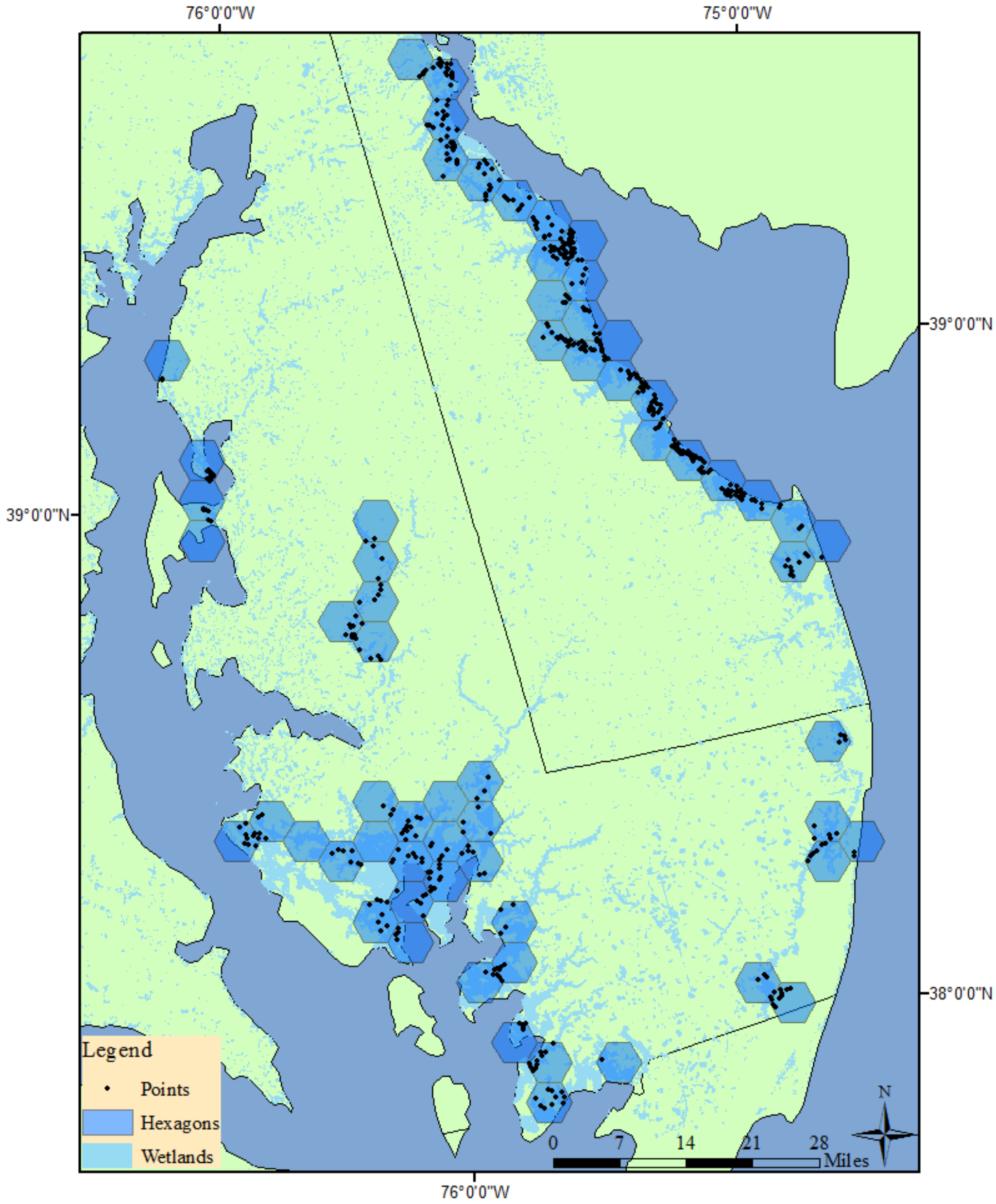

Figure 1.1 – Overview of All Points Sampled for Marsh Birds in the Delmarva Peninsula 2014-2015

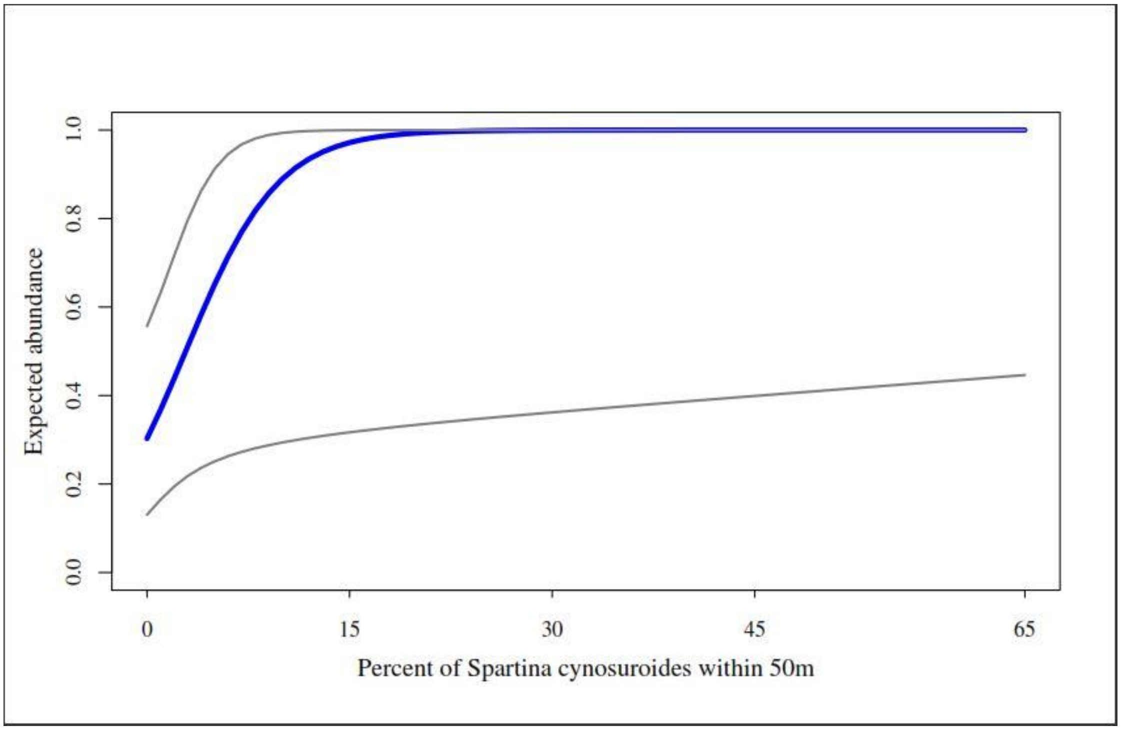

Figure 1.2 – Effect of *Spartina cynosuroides* on King Rail occupancy in the Delmarva Peninsula, 2014-2015.

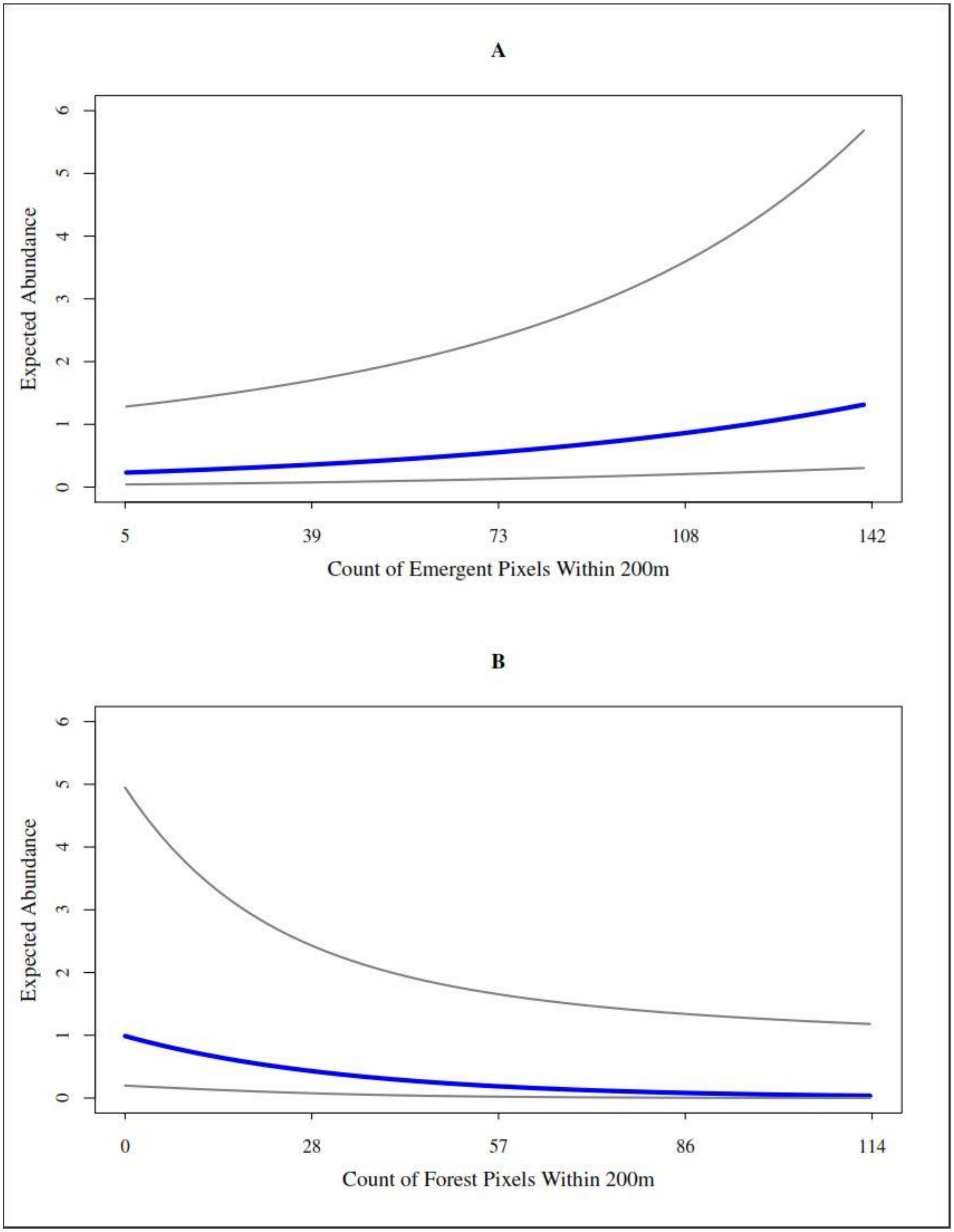

Figure 1.3 – Factors Influencing King Rail Abundance in the Delmarva Peninsula, 2014-2015. A.) emergent marsh, B.) forest cover.

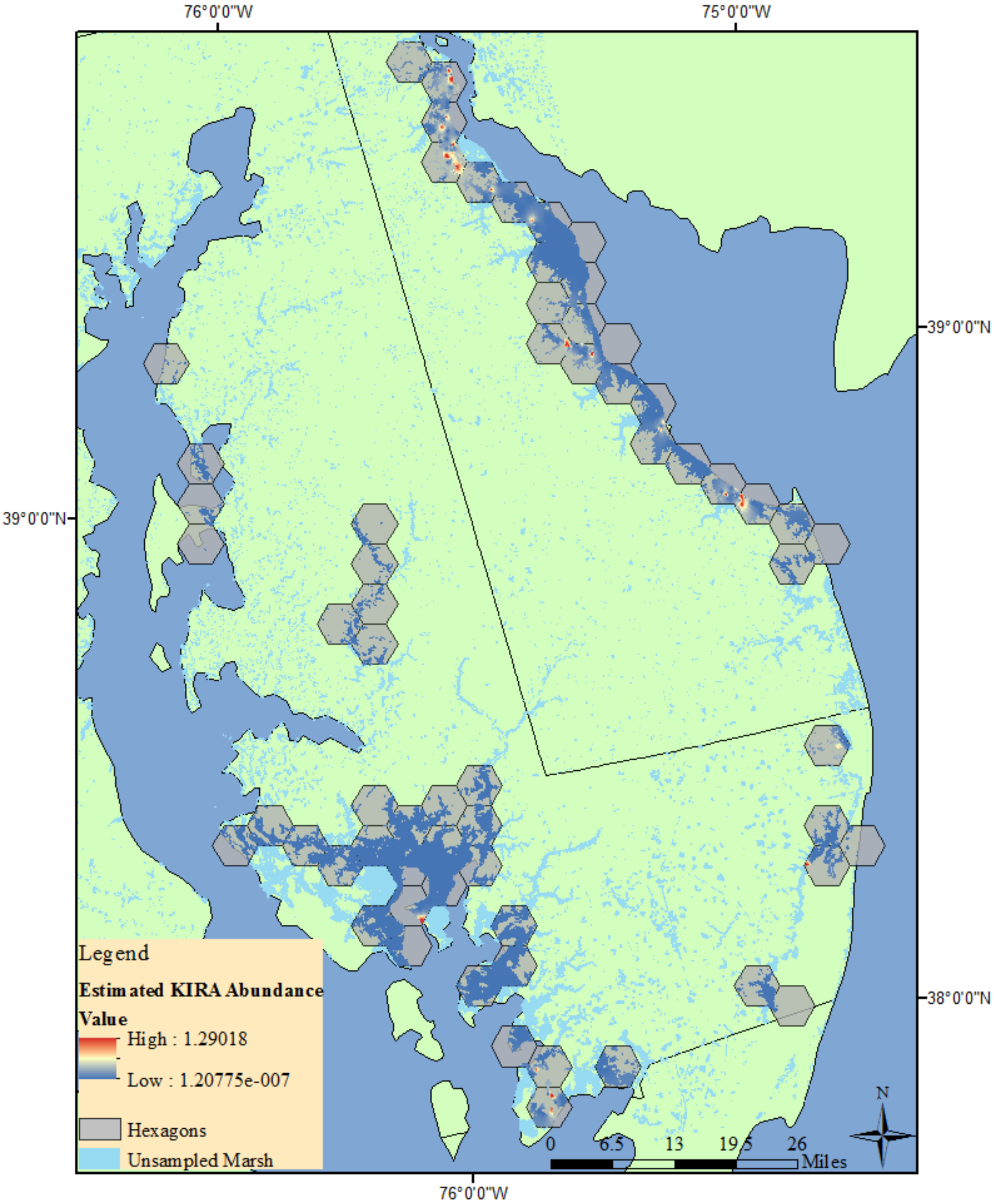

Figure 1.4 – King Rail abundance in the Delmarva Peninsula, 2014-2015, based on inverse distance weighted interpolation.

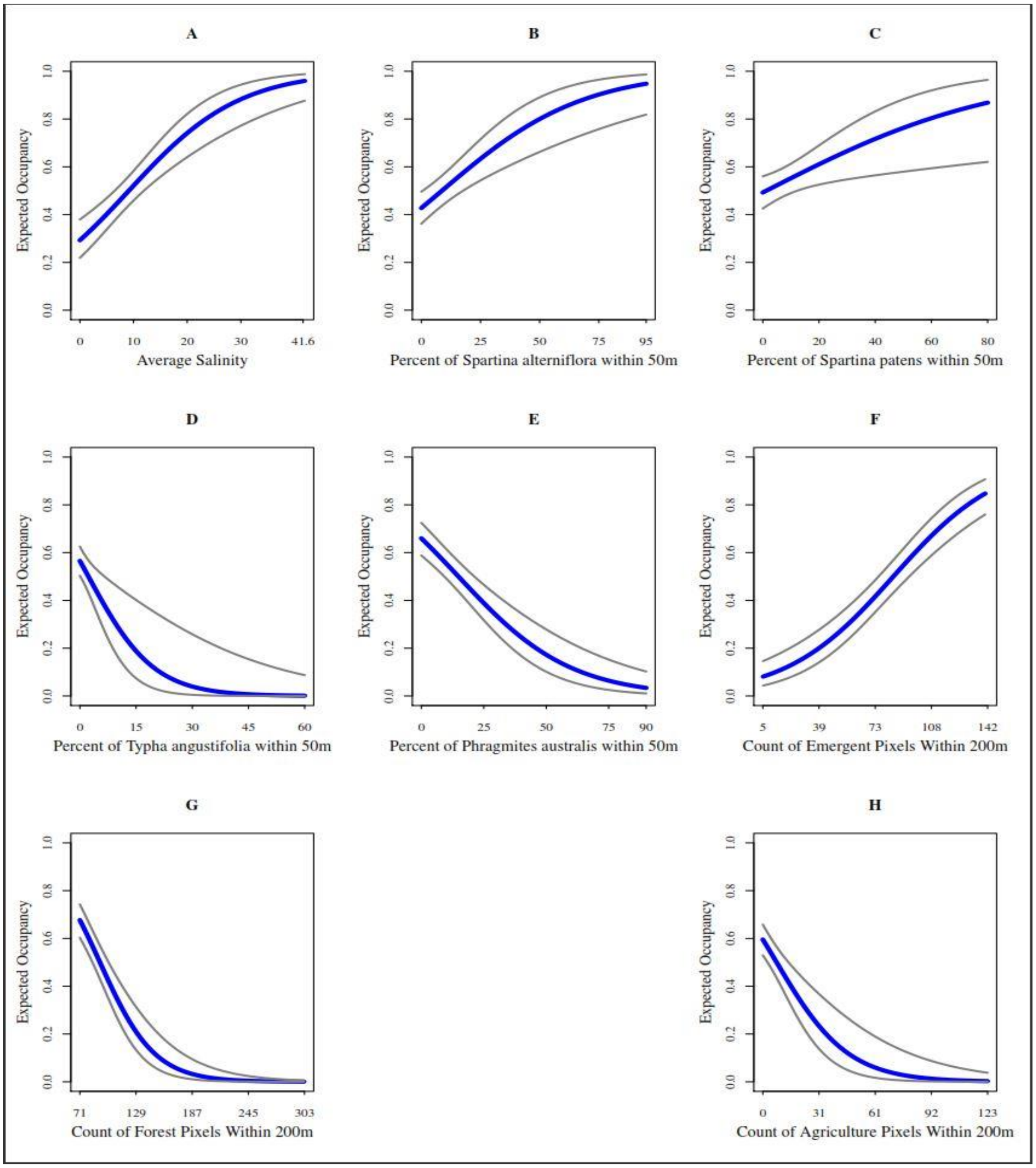

Figure 1.5 – Factors influencing Clapper Rail Occupancy in the Delmarva Peninsula, 2014-2015; A) salinity, B) *Spartina alterniflora*, C) *Spartina patens*, D) *Typha angustifolia*, E) *Phragmites australis*, F) emergent marsh cover, G) forest cover, and H) agriculture cover.

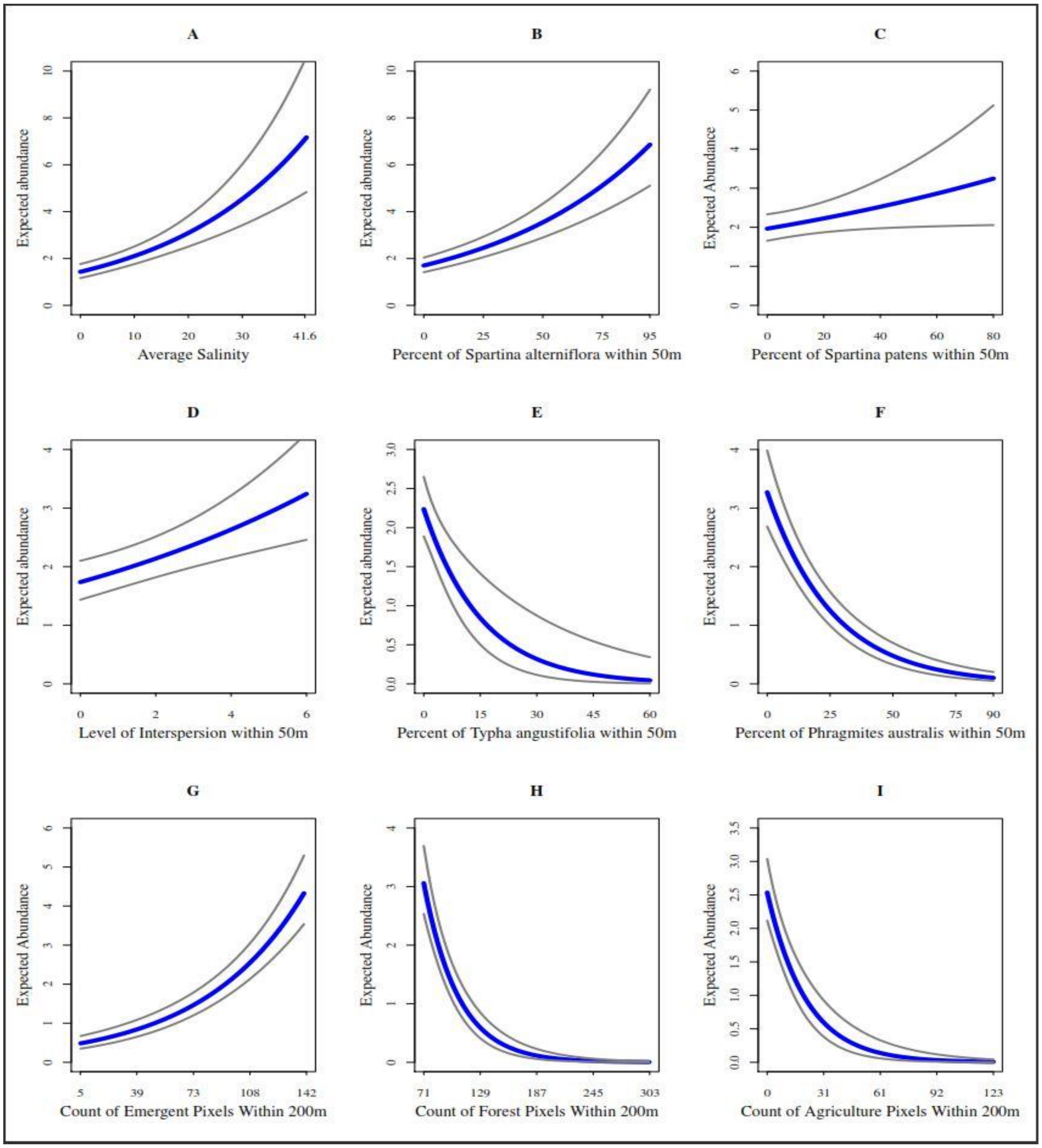

Figure 1.6 – Factors Influencing Clapper Rail abundance in the Delmarva Peninsula, 2014-2015; A) salinity, B) *Spartina alterniflora*, C) *Spartina patens*, D) interspersion, E) *Typha angustifolia*, F) *Phragmites australis*, G) emergent marsh cover, H) forest cover, and I) agriculture cover.

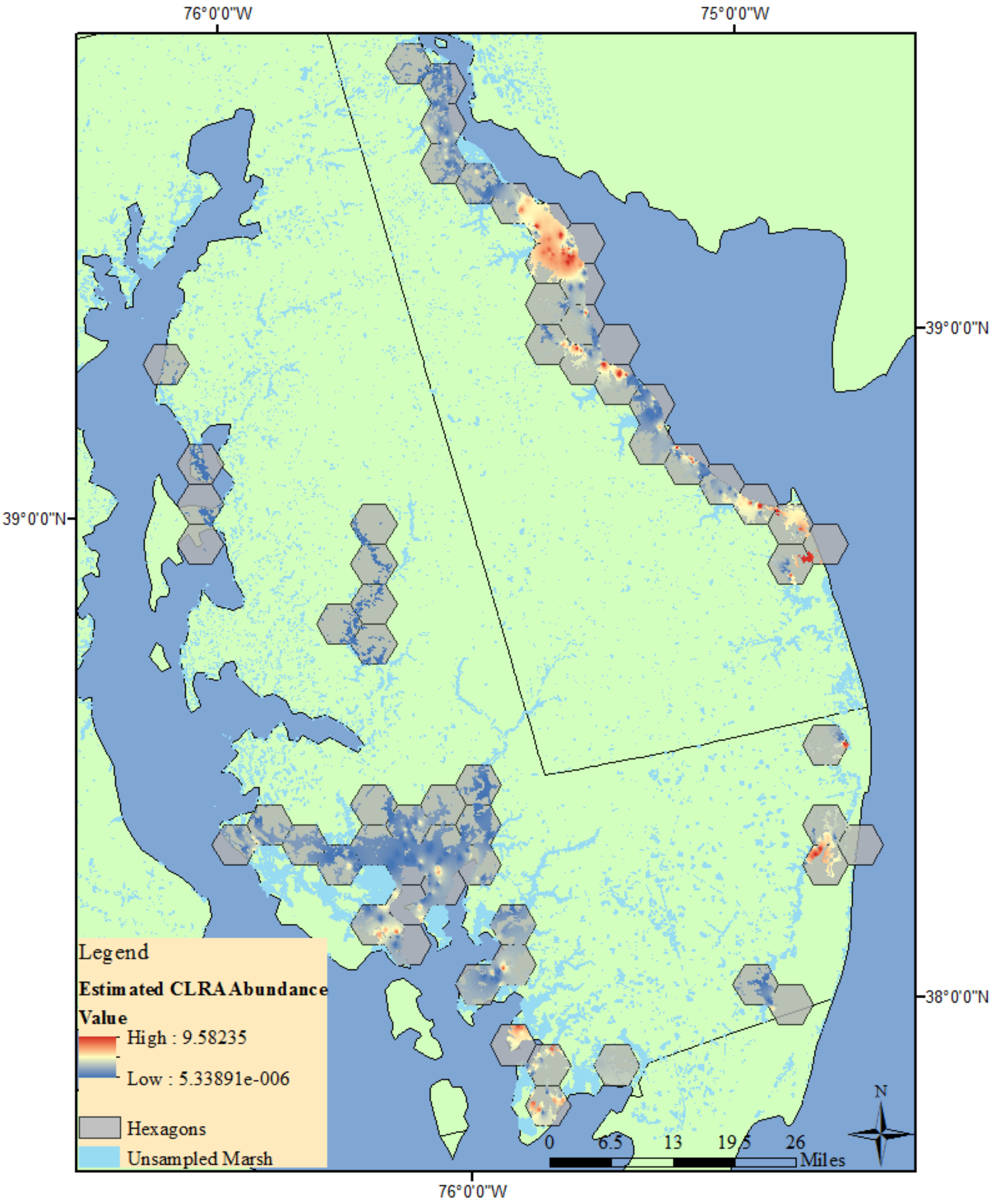

Figure 1.7 – Clapper Rail abundance in the Delmarva Peninsula, 2014-2015, based on inverse distance weighted interpolation.

CHAPTER 2:

USING MODIFIED ADAPTIVE SAMPLING PROTOCOLS TO INCREASE THE PRECISION OF ABUNDANCE ESTIMATES FOR KING RAIL (*RALLUS ELEGANS*)

INTRODUCTION

Obtaining reliable estimates of abundance is crucial for effectively monitoring and managing populations of rare organisms. This task becomes more challenging when species are rare, as the paucity of information leads to less precise estimates. In order to address this issue, various design frameworks have been proposed and implemented to increase the precision of estimates. Adaptive sampling is one class of methods used to increase the precision of estimates of abundance (Thompson 1990; Gattone et al. 2016). When adaptive sampling is employed, an initial set of units are selected in a systematic or random way. If a specified condition such as a high count of the organism of interest is met while surveying the initial sample, additional searching takes place nearby (Thompson 1990). This searching is generally done in the immediate vicinity of the initial unit sampled, and continues until no more units meet the condition to adapt or a predetermined stopping rule is met.

While adaptive sampling may seem intuitive, it adds upward bias to estimates because effort is increased in areas with relatively higher abundances of the specified organism (Salehi 2003; Thompson 1990). To alleviate this bias, data are adjusted using an unbiased estimator such as the Horvitz-Thompson or Hansen-Hurwitz estimators. These estimators take the inclusion probability of sampled units into account and adjust their weights accordingly. Using adaptive sampling methods has the potential to be much more efficient and to increase the precision of estimates over conventional means, provided certain conditions are met (Thompson 1990, Acharya et al. 2000). For adaptive sampling to be effective, the population must be rare and clustered on the landscape. If the organism is too common, then adaptive sampling will be triggered too easily resulting in more surveys than can be completed. If the organism is not clustered, additional searching in the neighborhood of occupied units will not result in more detections (Thompson 1990).

The king rail is an excellent candidate species for adaptive sampling techniques, as it is a rare species spatially clustered by the availability of suitable wetland habitat (Meanley and Wetherbee 1962; Wilson et al. 2007). Resident Mid-Atlantic king rails inhabit brackish and fresh tidal marshes, while the migratory interior race breed in fresh marshes (Bolenbaugh et al. 2012; Glisson et al. 2015). Suitable habitat for king rail in these areas is therefore scarce on the landscape, contributing to the species rarity. Clapper rail home-range sizes, a closely related species, have been shown to decrease with increasing densities of their arthropod food sources, suggesting that this guild may cluster around quality habitat (Rush et al. 2010). The king rail is declining throughout its range, which is probably a reflection of a decrease in the quantity and quality of king rail habitat (Sauer et al. 2014, Dahl 2011). Therefore, it is important that methods to obtain reliable estimates of population parameters are available. Our goal was to design and test an adaptive sampling methodology that builds on existing techniques which account for imperfect detection for monitoring marshbirds (Thompson 1990; Johnson et al. 2009; Royle 2004). As such, we employed a modified adaptive cluster sampling technique in which secondary sampling units were added to primary sampling units upon detection of a king rail. We also developed an adaptive neighborhood transect protocol which was employed following the detection of a king rail at a point.

METHODS

Survey Area and Point Selection

The marshes which encompass our study are located on the northern Delmarva Peninsula in the Delaware and Chesapeake Bays, particularly the brackish and fresh marshes therein (Figure 2.1). We focused on sampling brackish and fresh marshes because King Rails preferentially inhabit them as opposed to more polyhaline marshes (Meanley and Wetherbee 1962). We employed two-stage adaptive cluster sampling to generate secondary sampling units (points) in selected primary sampling units (40 km^2 hexagons) using a generalized random tessellation stratified (GRTS) approach (Wiest et al. 2016). All freshwater and estuarine marshes from the NWI wetlands layer were clipped to the hexagons to ensure that points were generated in suitable habitat (USFWS, 2010). An initial sample of five points was randomly generated or selected from historical points in the sampled hexagons. Our condition to adapt was the detection of a King Rail anywhere in the hexagon, at which point we intensified sampling effort in the hexagon (Thompson 1990a). An additional five randomly generated points were added in their draw order without replacement to every hexagon where a King Rail was detected. If another King Rail was found in one of the second stage adaptively sampled hexagons, a final five points were added for a total of fifteen points in a third stage adaptively sampled hexagon (Figure 2.2). We chose a stopping rule of ten additional points because in many instances there was an insufficient area of marsh to fit more than fifteen points in a hexagon while ensuring that they were spatially independent.

We selected primary sampling units based on the presence of historical King Rail sightings to maximize the detections for our search effort. This information was obtained by searching the Cornell Lab of Ornithology eBird database for records of King Rail within Delaware and Maryland (eBird, 2013). Additionally, data from previous marshbird surveys in the study area were collected from available sources. Primary sampling units with previous King Rail sightings were dropped for several reasons. If a hexagon did not have enough marsh to support a sample of at least five points it would be dropped. A hexagon may also be dropped if it did not contain enough brackish or fresh marsh to support breeding King Rails (i.e. – marsh entirely composed of saltmarsh). If a hexagon was too logistically difficult to sample because of travel time or property ownership issues it may be dropped as well. If a hexagon already had at least five points being sampled by a different project, additional points were not added to it. After taking these factors into account, we selected 17 primary sampling units in Maryland and 9 in Delaware.

Secondary sampling units in these hexagons were selected using a combination of existing historical points and new points generated using the GRTS technique.

Historical points were sampled preferentially if they were present in an effort to expand on existing datasets. We included a combination of both GRTS and historical points in our sampling regime in order to reduce bias of sampling areas. Most historical survey points fell on roadways and we wanted to sample in interior marshes away from the road as well. There were several rules which we followed in selecting secondary sampling units. When a hexagon had five or less historical points, those points were selected to be sampled and the remainder of the points would be GRTS points. In hexagons where there were five to ten historical points a random number would be assigned to each point, and the five points with the largest random numbers were selected for sampling. In hexagons with ten or more historical points, a coin would be flipped to determine whether to sample starting on the first or the second historical point in numeric order. From the start point the remainder of the historic points were selected in numerical order taking every other point in a random systematic sampling approach. No more than five historical points were sampled in any hexagon.

GRTS points were selected in the numerical order in which they were generated while maintaining an adequate buffer of at least 400m between the points. An initial sample of five GRTS points were chosen in the selected hexagons with no historical points or points sampled for a sister project. If a hexagon contained less than five points from either a sister project or historical points, the remainder of the points would be composed of GRTS points. The randomly generated points were dropped in some instances for reasons besides an inadequate buffer. If a point fell on private property or was generated within an inaccessible area of the marsh it was often dropped. If a point was dropped, the next sequential point was evaluated for access issues and either selected or dropped. A selected point was occasionally inaccessible but could be moved within 100m from the original location to gain access. In those instances, it would be moved to the nearest accessible point and the new coordinates were recorded. Historical points were not moved in order to retain fidelity to the original sampling location.

Point Count and Adaptive Transect Survey Protocol

Once points were selected in each hexagon, they were sampled according to the standardized North American Secretive Marshbird Survey Protocol (Conway 2011). This method of sampling employs a five-minute passive period followed by playback of all known breeding secretive marsh birds for a given region. The two regions that were sampled in this study were region 6 which consists of areas adjacent to the Delaware Bay, and region 8 which consists of the Delmarva Peninsula on the eastern shore of the Chesapeake Bay. We used a callback protocol according the SHARP methodology (Wiest et al. 2016). Surveys were conducted from a half hour before sunrise to 11:00 AM whenever possible. We did not survey during periods of soaking rain or when the sustained winds were above a 4 on the Beaufort wind scale. Birds of all species heard or seen using the marsh were counted in the minute they were detected. All birds using the marsh were broken into three distance bands: 0-50m, 50-100m, and greater than 100m. Focal species were secretive marsh birds suspected to breed in the region. If a focal species was detected, additional information was recorded regarding the detection. Observers estimated the exact distance to the calling SMB in addition to recording the distance band into which it fell. Information on whether the bird was seen or heard was recorded, as well as the call type. The duration and rate of aural and visual detection were recorded in each time period that a focal species was seen or heard.

If a King Rail was detected at a survey point, an adaptive neighborhood line transect survey was initiated. This methodology is similar to other studies using adaptive transect surveys, except that our study collected the transect data as an extra piece of information to supplement our point count data (Pollard, Palka, and Buckland 2002; Palka and Pollard 1999). When a King Rail was detected at a point, the point count was completed before beginning the transect survey. To determine the transect orientation, a random bearing was selected along a 180 degree arc in which the direction of the first King Rail detected during the point count was the midpoint of the arc. If the marsh was either on private property or was not traversable then we selected the most traversable direction. In some instances this was through the marsh, and in other instances we ran the transect survey by kayak along a nearby creek. The adaptive transect survey was characterized by 30 seconds of King Rail playback at the origin, followed by 30 seconds of silence. The observer then traveled 50 meters along the transect line and repeated the 30 second King Rail playback followed by 30 seconds of silence. This action was repeated until 200 m or an insurmountable obstacle was reached, at which point the coordinates of the end point of the transect survey were recorded. At the end point of the transect, a two-minute passive period was initiated followed by a minute of King Rail playback and another two minutes of silent listening. After this was completed, the observer would turn 90 degrees in a randomly selected direction and walk 50 meters and repeat the transect protocol back towards the original point (Figure 2.3). Any focal species detected during the transect survey were recorded along with the estimated distance and orientation from the point of first detection in order to facilitate distance sampling (Royle 2004; Buckland et al. 2009). Observers kept track of all individuals to account for movement during the transect survey, and marked each interval it was present. If a focal species was detected while walking in between two points, it would be added to the next point along the transect survey and its distance and orientation would be estimated from that point. Call types and whether the bird was detected aurally or visually were recorded as well.

Analysis of Adaptive Cluster Sampling Data

Our adaptive cluster design is different from many other designs, because we selected points which were not adjacent to each other when our condition to adapt was met. Most studies employing adaptive cluster sampling enumerate all units in the immediate neighborhood of a unit in which the condition to adapt is met (Thompson 1990; Thompson 1991; Acharya et al. 2000; Gattone et al. 2016). Sampling in neighboring units is done in a systematic way until no more units satisfy the condition to adapt, creating a network consisting of adjacent units that meet the condition and the edge units which do not. These studies then use methods to assess the inclusion probability of units within the networks, and adjust the weight of those units to account for the bias which is introduced by sampling in areas with a higher than average abundance. In contrast, our study is design unbiased at the level of the primary sampling unit. This is because adaptively sampled secondary units are added in a spatially random way, allowing for unbiased inference across the entire area of each primary sampling unit. That being said, if we were to try to estimate a population mean for our sample area by using all points it would introduce upward bias because hexagons with King Rail detections contain more points.

Our goal was to increase precision of the abundance estimates within hexagons that contained King Rails by adaptively intensifying effort in primary sampling units that satisfied our condition to adapt. We used a multinomial N-mixture removal model implemented in the unmarked package in program language R to estimate the abundance of King Rails in sampled hexagons (Royle 2004; Fiske and Chandler 2011). This model uses a hierarchical model structure to model the detection and abundance processes separately. A time of detection removal model is used to calculate the detectability of an individual, in that once an individual was detected it is removed from the survey and not counted again. We used detections within 100 meters of the observer to limit the amount bias introduced by the variable detectability of species beyond 100 meters (Wiest et al. 2016; Buckland et al. 2009), to maximize the number of rail detections (Valente et al. 2011), and to maintain independence among points. We analyzed the data for 2014 and 2015 together then report on the average abundance estimate for each hexagon in the two year period. This was done in order to maximize the amount of data used, as detections of King Rails were sparse in our dataset.

Analysis of Adaptive Line Transects

As stated previously, the transect data were collected as supplemental information regarding the abundance at sites occupied by King Rails. Because only sites which were occupied had transects completed at them, the inference cannot be extended beyond occupied sites in our study area. The abundance estimates obtained from the transect data represent the average estimated abundance at occupied sites within our survey area. We analyzed the transect data using generalized hierarchical distance sampling using the ‘gdistsamp’ function in package unmarked (Chandler et al. 2011; Fiske and Chandler 2011). The generalized distance sampling model relaxes the assumption that each transect is independent, allowing for inference from more than one transect collected at one point. Information from multiple visits to the same point is used to estimate availability of birds for sampling, and distance information is used to estimate the detection probability of birds. This model also relaxes the assumption that the probability of detecting a bird zero meters away from a transect is one, which is realistic given the dense growth form of most emergent marsh vegetation and the secretive nature of King Rails. In order to evaluate the effectiveness of the adaptive transects at increasing the precision of the abundance estimates, we compared the estimates from the transect data to the estimates from the point count data collected at sites with adaptive transects. The point count data was analyzed using the multinomial removal model and a repeated visit model in unmarked (Fiske and Chandler 2011; Royle 2004).

RESULTS

Adaptive Cluster Sampling

The condition to adapt was met in 6 out of 9 hexagons in Delaware, and only in 1 out of 17 hexagons in Maryland. In Maryland a king rail was heard outside of a survey in one of the adaptively sampled hexagons in the Choptank River, prompting the addition of 5 extra survey points to the hexagon. Subsequent surveys in the area did not yield additional King Rail detections. There were no King Rails detected during surveys in adaptively sampled hexagons in Maryland in 2014 or 2015, so abundance was not estimable for this region. In Delaware, all 6 hexagons in which a King Rail was found yielded at least one more King Rail detection which led them to contain 15 sampling points each. There were 48 King Rail detections in adaptively sampled hexagons in Delaware during the 2014 and 2015 field seasons combined, 29 of which were within 100 meters of the surveyor. Estimated abundances for adaptively sampled hexagons in Delaware are shown in Table 2.1.

Estimated abundances and standard errors did change slightly with the addition of extra sampling points. The standard error decreased from the initial sample to the final sample in 3 out 4 hexagons for which abundance was estimable. The standard error increased for one of the adaptively hexagons for which abundance was estimable. In two of the adaptively sampled hexagons, abundance estimates were increased as a result of more occupied points being added to the sample. In another two hexagons the estimated abundance decreased with the addition of over sample points as a result of unoccupied sites being added to the sample. In the other two hexagons in which adaptive sampling was initiated, the estimate of abundance was zero for all stages of over sampling. This was either due to the fact that King Rails were detected further than 100 meters away from the points, or that King Rails were not detected during the surveys. The 95 % confidence intervals for the estimated abundance in all hexagons overlapped between treatments. This suggests that adaptively adding randomly generated sampling points to 40 km$^{\wedge 2}$ hexagons may marginally increase the precision of abundance estimates and lead to more detections of the species of interest.

Adaptive Transects

In the 2014 and 2015 field season, there was a combined total of 30 adaptive transects completed at 21 points in Delaware. There were 7 points which received more than one transect, and two of those points had three transects completed during the two-year period. The third transects were dropped from analysis because they resulted in too many additional missing values to calculate reasonable results. There were 58 King Rail detections at all transects combined. The average time taken to complete a full 450 meter transect through the marsh was 61.3 minutes. The average length of an adaptive transect was 370.9 meters. There were three transects which did not have any King Rail detections, despite there being a King Rail detection during the point count prior to the transect survey. All transects were combined and analyzed in order to obtain an estimate of the average abundance for all occupied points in the survey area. These results were compared to the average abundance estimates for the same points calculated using the point count protocol. The estimates of the average abundance of occupied sites and associated standard errors for all methods are shown in Table 2.2. The adaptive transects had the lowest standard error out of any of the techniques, with an abundance estimate of 0.216 ± 0.041 King Rails per hectare on average at occupied sites. Results from the repeated count method were unreasonable. The removal model performed alright but yielded a higher standard error than the transect data with an abundance estimate of 0.127 ± 0.059 King Rails per hectare on average at occupied sites.

DISCUSSION

Using adaptive cluster sampling in the manner in which we did increased the precision of our abundance estimates only marginally. This is probably a result of the large area over which points were adaptively added to. Although this method of adding points did enable us to estimate unbiased average abundance over the area of the hexagons, the addition of points over the entire area of the available marsh in each hexagon did not result in a sufficient amount of additional King Rail detections to significantly increase the precision of our estimates. It is possible that reducing the areal extent of the adaptively sampled neighborhood would result in a larger increase in King Rail detections. If the neighborhood of each point was defined to be the marsh patch in which it is contained for instance (Wiest et al. 2016), adaptively sampled points could be added to the marsh patch to which it belongs. In this way, the adaptively sampled points would be spatially constrained to be closer to the area containing King Rails and may be more likely to yield additional King Rail detections.

If marsh patches were used as the neighborhood of an adaptively sampled point, unbiased estimators like the Horvitz-Thompson or Hansen-Hurwitz must be used to get an unbiased estimate of the hexagon level abundance (Thompson 1990). One challenge of applying the adaptive cluster sampling technique to secretive marshbirds is the need to account for bias introduced from multiple sources (Thompson 1990; Conway 2011; J. A. Royle 2004). The elusive nature of marshbirds and many other species dictates the use of methods which account for imperfect detection (J. A. Royle 2004). If the imperfect detection of secretive species is ignored, it can lead to downward bias in estimates of abundance. When systematic adaptive cluster sampling is employed, it introduces upward bias to population estimates by increasing sampling effort in areas with higher abundance (Thompson 1990). To my knowledge, no unified statistical framework currently exists which accounts for bias introduced both from imperfect detectability and from adaptively sampling in areas with higher relative abundance. Our study design attempted to obviate the need for adjusting estimates of abundance for unequal survey effort at the level of the primary sampling unit. While we were successful in achieving this, our methodology failed to produce an appreciable increase in the precision of our estimates.

Adaptive neighborhood transects analyzed using distance sampling techniques were effective at increasing the precision of King Rail abundance estimates of occupied sites compared to traditional point count techniques. This technique results in an average estimate of abundance over all occupied sites, which is an admittedly biased measure because unoccupied sites are ignored. However, generating precise estimates of abundance from sparse data is a challenging endeavor. Because the points with transects are repeatedly sampled from year to year, this technique could be used to estimate changes in population size at these sites by conducting the adaptive transects at them each year. The increased precision of the transect surveys would result in a greater power to detect changes in abundance at sites with King Rails, which could be a reflection of population changes across the survey area. If sufficient transect data is collected at smaller spatial scales such as the hexagons in our study, changes in metapopulation dynamics within occupied areas could be revealed.

The adaptive transects may have yielded increased estimates of abundance at occupied points and decreased error associated with these measures for several reasons. When observers conducted adaptive transects at points, they spent an average of four times as much time conducting the transect compared to the point count giving them more time to detect rails present in the area. The transect surveys also covered a larger area than the point counts, and they involved the use of conspecific playback while potentially crossing territory boundaries of rails adjacent to the point count. This may have caused birds which would not call during the point count survey to respond to a perceived intruder to their territory. Finally, the adaptive transects utilized all detections regardless of distance from observer whereas point counts only used detections within 100 meters of the point in order to meet the assumption that detection probability is constant at a point count (Wiest et al. 2016; Chandler, Royle, and King 2011). Methods which combine traditional analysis of point counts and distance sampling would enable the use of more detections, which could improve the precision and accuracy of abundance estimates from point counts (Amundson, Royle, and Handel 2014).

Implementation of the transect surveys in the marshes of our study unit was challenging, and consideration of these challenges and other potential drawbacks of adaptive transect surveys is necessary before implementing them in other field situations. Traversing the marsh in our study area was sometimes difficult or impossible by conventional means, leading to many transects which had to be cut short due to an obstacle in the way. In studies conducted in areas with hazardous terrain, use of adaptive sampling transects may be dangerous and ill advised. If the habitat being sampled is sensitive to trampling, the risk of habitat damage should be carefully considered.

In studies like ours which use prior records of species occurrence to select sampling areas, sightings should be carefully vetted to ensure the best available information is used. For surveys of breeding birds, using only sightings during the breeding season of the species studied is recommended as habitat use may vary between the breeding and non-breeding seasons. Historical records are often from more accessible areas, which can lead to bias from the unequal coverage. Studies wishing to estimate the total population size of an organism should sample in less accessible areas of suitable habitat that may not contain prior records in order to account for this bias. Stratification of sites based on the presence or amount of historical records could be used to achieve this (Wiest et al. 2016).

The fact that we did not detect any King Rails in 17 adaptively sampled hexagons in Maryland is significant. Many of these sites were selected based on prior knowledge of breeding King Rails in the sampled areas (Wilson, Watts, and Brinker 2007, Meanley 1975). That we found no King Rails in these areas suggests that there may be a marked decline in the populations here. This is consistent with the findings of Brinker et al, who found King Rails to be sparse in historic strongholds in the region (Brinker et al. 2002). The only place which held abundant populations in that study was the Choptank River, where we had only one detection of a King Rail. Meanley pointed out that the Nanticoke river contained a healthy population of breeding King Rail, but we failed to find any King Rail in this area (Meanley, 1975). It has been suggested that clapper rails may be displacing King Rails in the Chesapeake Bay as a result of changing habitat, and we found some evidence of that in our surveys (Brinker et al. 2002). However, we did not find many clapper rails in the Chesapeake either, suggesting there may be another underlying cause of these declines. Brinker et al. suggested that a study of the arthropod abundance and diversity in the marshes of the Chesapeake be conducted. This may be advisable because it has been shown that clapper rail home ranges are smaller in areas of high prey density, leading to higher rail densities (Rush et al. 2010). Anecdotally, we found more red-jointed fiddler crabs (*Uca pugnax*) in Delaware Bay marshes than in Chesapeake Bay marshes. This species is a very important food source for king and clapper rails during the breeding season in Delaware (Meanley and Wetherbee 1962). This difference in prey availability could be driving the difference in relative abundance of king and clapper rails between the Delaware Bay and the Chesapeake Bay.

There are further lines of evidence that support this hypothesis. The Chesapeake Bay is well known to have high levels of anthropogenic chemical inputs from industry and agriculture (Paolisso et al. 2015). Increasing inputs of nutrients from runoff of fertilizer can cause cultural eutrophication leading to anoxic conditions that are detrimental to aquatic organisms (Dala-Corte et al. 2016). This could be resulting in depressed population levels of the aquatic invertebrates necessary for the survival of rails. We found that clapper rail abundance in the Delmarva was negatively correlated to the amount of agriculture within 200 meters of a point (Freiday et al. unpublished data). This could be a byproduct of the fact that these areas have higher than average chemical inputs resulting in lower than normal populations of rails and their food sources. The Delaware Bay is also subject to high levels of anthropogenic pollution (Hartwell and Hameedi 2006). However, the effects of low oxygen levels in the water may be alleviated by the fact that the tidal range in the Delaware Bay is higher, leading to a more well mixed estuary (Sarin and Church 1994). Clearly, more research is necessary to determine the underlying causes of the marked decline in King Rail populations in the Chesapeake Bay region. The use of our adaptive sampling protocols may aid in quantifying these trends more precisely.

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Table 2.1 - King Rail Abundance Estimates in Adaptively Sampled Hexagons in DE, 2014-2015.

	Final Oversample		First Oversample		Initial Sample	
Hexagon	Birds/ha	SE	Birds/ha	SE	Birds/ha	SE
236147	0.059	0.031	0.053	0.029	0.047	0.033
236933	0.074	0.035	0.04	0.025	0.024	0.024
238900	0.015	0.011	0.013	0.01	0.024	0.017
69910	0.037	0.024	0.033	0.022	0.053	0.034
236540	0	0	0	0	0	0
67157	0	0	0	0	0	0
238114	NA	NA	NA	NA	0	0
68377	NA	NA	NA	NA	0	0
70304	NA	NA	NA	NA	0	0

Table 2.2 - Average Abundance Estimate for Points with King Rail Adaptive Transects

Analysis Method	Function	Density Estimate (KIRA/ha)	SE
Distance Sampling	gdistsamp	0.216	0.041
Repeated Visits	pcount	12.013	85.645
Removal Sampling	multinomPois	0.127	0.059

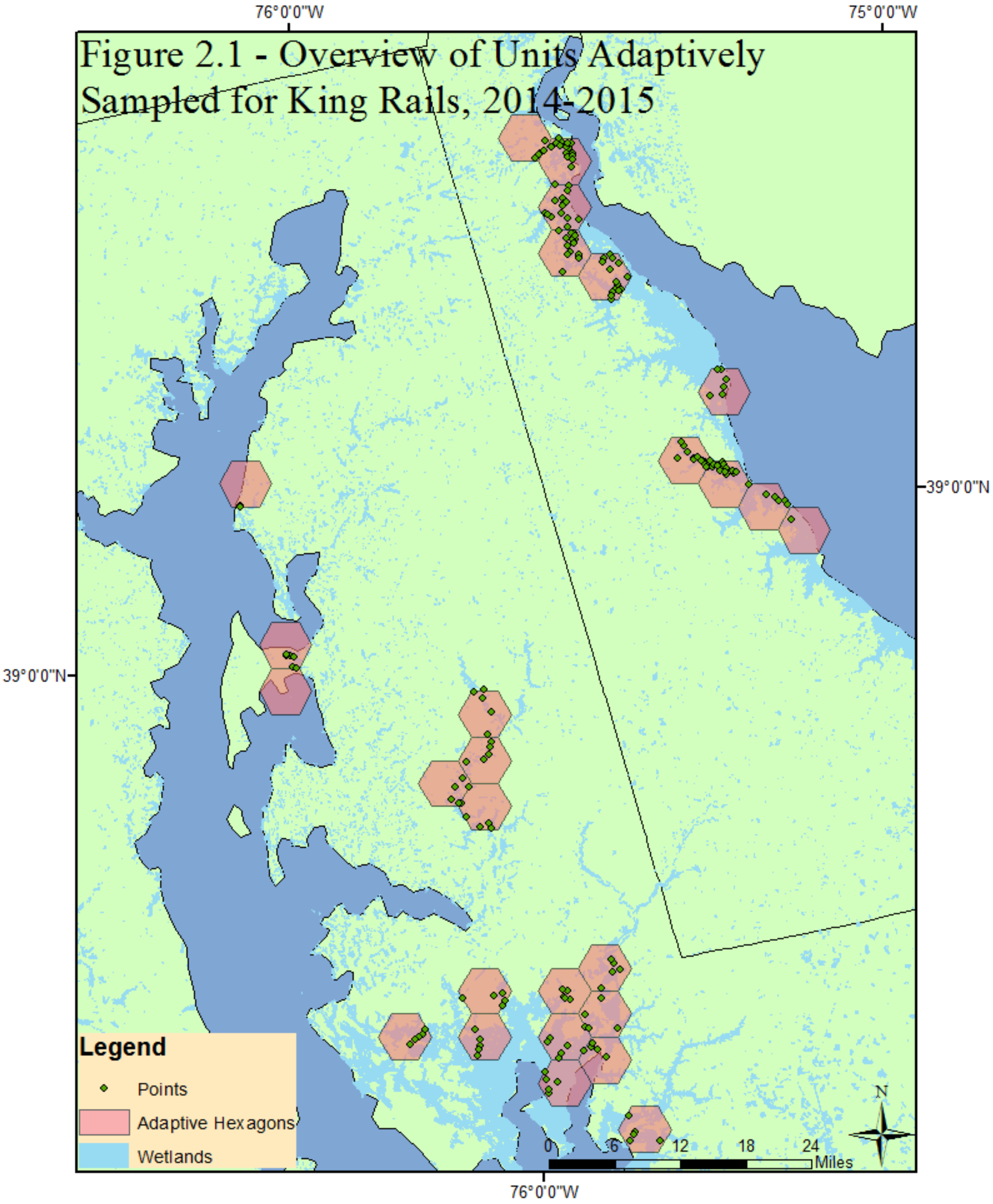

Figure 2.1 – Hexagons using adaptive sampling for King Rails, 2014 – 2015.

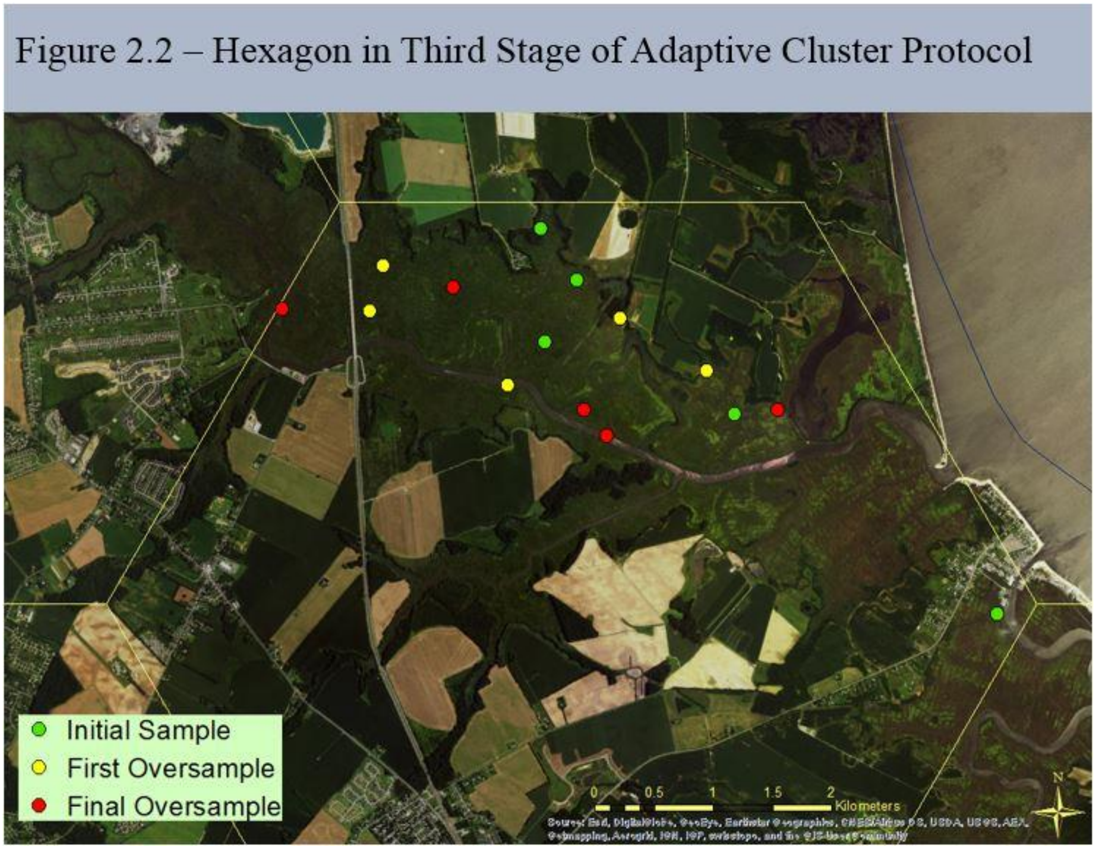

Figure 2.2 – Hexagon in Third Stage of Adaptive Cluster Protocol

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 2.2 – Example of adaptive over-sampling.

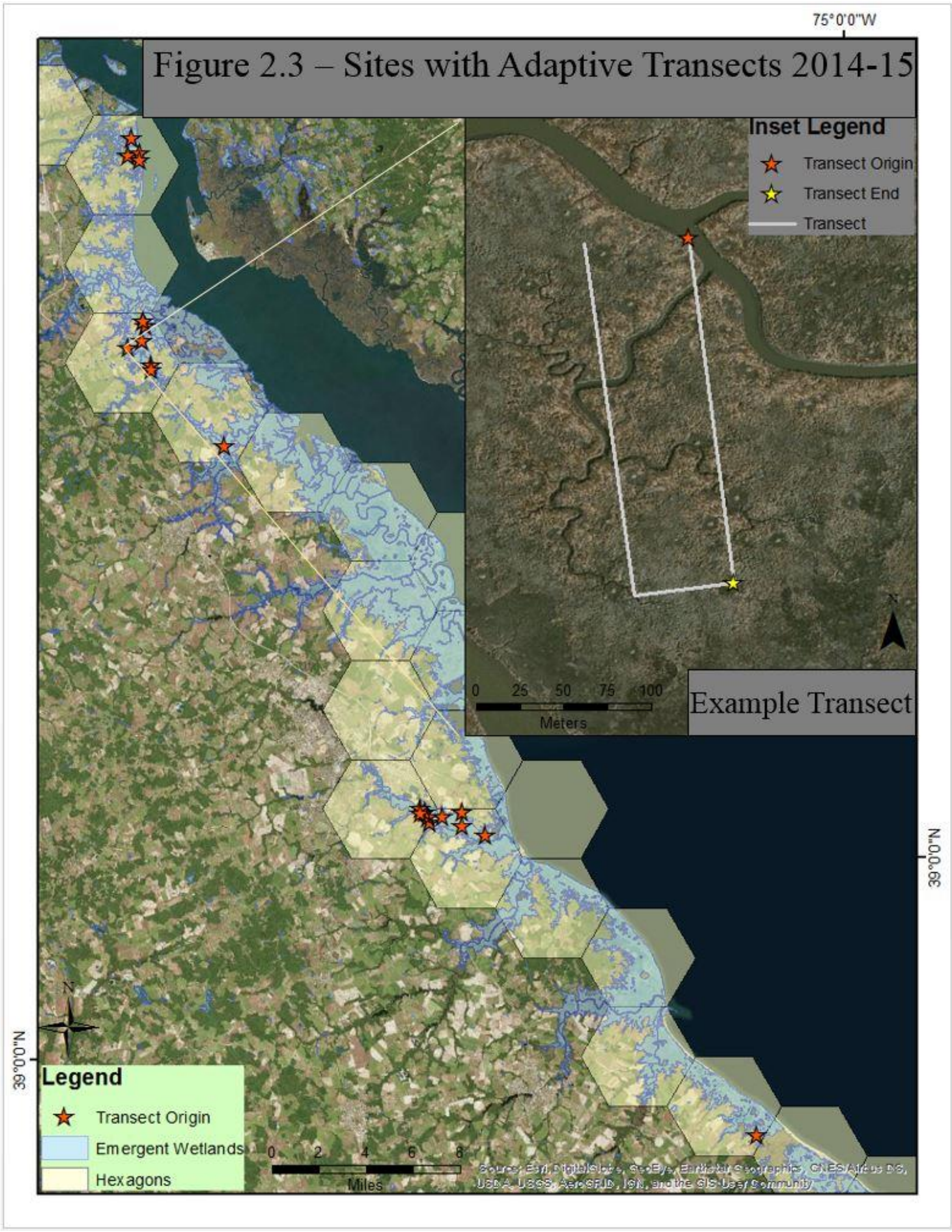

Figure 2.2 – Sites where King Rails were detected and adaptive sampling was implemented.