ABUNDANCE AND DISTRIBUTION OF SECRETIVE MARSH BIRDS AND METAL CONTAMINANT, BIOCHEMICAL, AND CELLULAR BLOOD LEVELS OF CLAPPER RAIL (*RALLUS CREPITANS*) WITHIN JACKSONVILLE, FLORIDA

by

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(Under the Direction of Jeffrey Hepinstall-Cymerman, Susan Wilde)

ABSTRACT

Secretive marsh birds are a guild of species for which baseline and overall population trends are lacking. Avian surveys were conducted in Florida to estimate abundance for eleven species of marsh birds, using the Standardized North American Marsh Bird Monitoring Protocol. Multiple scales ranging from 0.785-7,850 ha were used in conjunction with single-season N-mixture models to estimate abundance. There were discrepancies between years in top models, but results in general were consistent with other studies and top models included variables from multiple scales. Clapper rail blood and invertebrate samples were tested for heavy metal contaminants, and several birds exhibited levels above known toxic thresholds. Invertebrate levels were within the range of other reference levels. Complete blood counts and biochemistry panels were measured to assess clapper rail health, and findings were mostly within normal ranges for species within the same order.

INDEX WORDS: Abundance, distribution, N-mixture model, multiple scale, Standardized North American Marsh Bird Monitoring Protocol, clapper rail, heavy and trace metals, biochemistry, complete blood count

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DEDICATION

I dedicate this thesis to all that have helped me throughout my professional career and personal life; especially my husband, Marc Beechuk. You have worked tirelessly to provide for me and our menagerie of animals while I have been in school, and none of this would have been possible without the support and patience I have received.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Introduction and Literature Review

The state of Florida is home to a variety of wetland habitats. The types of wetlands are incredibly diverse and include freshwater wetlands, forested wetlands such as mangrove and cypress swamps, wet prairies, and coastal wetlands (Dahl, 2005). Coastal wetlands are also known as tidal marshes and include freshwater, marine, and estuarine wetlands (Dahl and Stedman, 2013; Tiner, 2013). In the state of Florida, approximately 10% of total wetland acreage is considered either marine or estuarine wetlands (Dahl, 2005). The term 'estuarine wetland' can be defined in multiple manners; but in general, it refers to an area where saltwater from the ocean intermixes with freshwater from terrestrial sources (Dahl and Stedman, 2013; Tiner, 2013). Salt marshes form on the edges of these estuaries, and represent transition zones between open ocean and terrestrial habitats (Florida Department of Environmental Protection, 2015). Salt marshes occur all over coastal areas within the United States, but are most extensive along the Atlantic coast from Maine, and throughout the gulf states (University of Florida IFAS Extension, 2002).

Several abiotic processes drive the formation and resulting pattern of salt marshes: tidal regime, winds, waves, currents, and sedimentation rates (Dahl and Stedman, 2013; Tiner, 2013). The hydrology and tidal regime are the primary forces responsible for producing the intertidal and subtidal zones seen within tidal marshes (Tiner, 2013). The hydrologic and tidal regime also affects the degree of salinity which dictates the resulting diversity and structure of vegetation communities (Tiner, 2013). Plant species living within tidal marshes are halophytic, or salt tolerant. Typical halophytic species found in salt marshes in northern Florida include: smooth cordgrass (*Spartina alterniflora*), black needle rush (*Juncus romerianus*), saltwort (*Batis maritima*), saltgrass (*Distichlis spicata*), and other epiphytes. Low marsh zones are the lowest elevations, and are typically a monoculture of smooth cordgrass (*Spartina alterniflora*) (Tiner, 2013; United States Fish and Wildlife Service, 2011). These low marsh areas are regularly inundated by tides, so resulting plant communities must be adapted to dynamic environments. Moving into the higher marsh zones, a shift in the plant communities emerges: black needle rush (*Juncus romerianus*), salt hay grass (*Spartina patens*), grasses, and forbes become the predominant plant communities (Brody, 1994; Tiner, 2013). Despite their low plant diversity and species richness, primary productivity rates in wetlands are some of the highest in the world (Keddy, 2010). This high level of productivity is in part what makes coastal wetlands so invaluable, both to humans and ecological communities.

Tidal marshes provide resources to both resident and migratory bird species which use tidal marshes for some portion of their annual lifecycle. There are several species that are critically reliant upon tidal marshes; secretive marsh birds (hereafter SMBs) are one such guild of species, and are the focus of this research project. Historically, wetlands were thought of as waste lands (Florida Department of Environmental Protection, 2015). Perspectives have changed, however, as society began to realize that the benefits afforded by coastal marshes are many. The primary productivity serves as the building block for estuarine food webs (Tiner, 2013). Estuarine food webs provide resources not only to wetland flora and fauna, but also to humans as well. Specifically, tidal marshes act as nurseries for a plethora of fish and invertebrate species, several of which are of commercial importance in northern Florida. These include species such as blue crab (*Callinectes sapidus*), shrimp (Penaeus spp.), and mollusks (Mercenaria spp., and Crassostrea spp.) (Brody, 1994).

Additionally, wetlands influence processes at large scales, such as climate worldwide. Wetlands sequester atmospheric carbon dioxide and produce methane; two greenhouse gasses which are directly associated with global temperature fluxes (Keddy, 2010). Wetlands also have a role in improving water quality; wetland vegetation aids in decreasing turbidity, filtering contaminants, and denitrifying waters, which can help offset eutrophication processes (Keddy, 2010; Tiner, 2013). The physical presence of wetlands on the landscape serves as a barrier to extreme flood events, storm surges, and shoreline erosion (Keddy, 2010; Tiner, 2013). Lastly, wetlands provide cultural, recreational, and aesthetic value. Despite their enormous importance economically and ecologically, the fate of coastal wetlands is uncertain, due to many factors which are discussed below.

As of 1996, it was estimated that approximately a third of (4.6 million ha) of the land area of Florida was classified as some form of wetland. However, it is estimated that only 56% of this original wetland acreage still remains (Dahl, 2005). Wetlands have been subjected to draining and dredging operations, and it is estimated that 8% (~60,000 acres) of estuarine wetlands were lost due to these activities. The northeast counties of Florida represent approximately 11% of the state's total salt marsh acreage. Both Nassau and Duval counties, the study area for this project, have lost wetland acreage to dredge and fill activities. The Florida Marine Research Institute quantifies changes in the areal extent of wetlands by examining aerial photography from the 1940's onwards. According to this analysis, there has been a 36% loss of salt marsh habitat within the St. Johns river (Duval county) since 1943 (Florida Department of Environmental Protection, 2015). This local trend observed in Florida also echoes a nationwide trend as well; a study conducted from 1998-2004 estimated a net loss of 361,000 acres of coastal wetlands in the eastern United States (Dahl and Stedman, 2013).

The amount of wetlands continue to decline due to the continuation of activities such as draining and ditching, filling, channelization, alteration of hydrologic regime, and other anthropogenic disturbances. Land conversion and sea-level rise have serious implications for the persistence of coastal marshes; when the landscape surrounding marshes is heavily developed, it does not allow for the expansion and normal successional stages of marsh development to proceed. As a result, existing wetlands are essentially trapped since they simply have no place to expand (Dahl and Stedman, 2013; Tiner, 2013). Anthropogenic activities are the primary cause of degradation of wetlands; contaminants from urban, agricultural, and industrial operations all affect the stability and integrity of marsh systems (Lopez et al., 2006; Tiner, 2013). The same issues that threaten the long-term persistence of coastal marshes are relevant for their inhabitants as well.

SMBs are a guild of species which exhibit cryptic behavior, are wetland dependent, and poorly understood (Conway, 2011; Eddleman et al., 1994; Pickens and Meanley, 2005; Poole et al., 2009; Ribic, 1999; Rush et al., 2012). The state of Florida provides over-wintering, migratory, and/or breeding habitat to numerous species of SMBs: American bittern (*Botaurus lentiginosus),* American coot (*Fulica americana*), black rail (*Laterallus jamaicensis*), clapper rail (*Rallus crepitans*), common gallinule (*Gallinula galeata*), king rail (*Rallus elegans*), least bittern (*Ixobrychus exilis*), limpkin (*Aramus guarauna*), pied-billed grebe (*Podilymbus podiceps*), purple gallinule (*Porphyrio martinicus*), sora (*Porzana carolina*), Virginia rail (*Rallus limicola*), yellow rail (*Coturnicops noveboracensis*), marsh wren (*Cistothorus palustris*), Nelson's sparrow (*Ammodramus nelsoni*), saltmarsh sparrow (*Ammodramus caudacutus*) and seaside sparrow (*Ammodramus maritimus*). The following species are known to breed on the Atlantic coast side of northern Florida: black rail, clapper rail, king rail, marsh wren, and least bittern (Eddleman et al., 1994; Kroodsma and Verner, 2013; Pickens and Meanley, 2005; Poole et al., 2009; Rush et al., 2012). As the term SMBs implies, these species require wetland habitat for all aspects of their life histories. Since wetlands are a requirement for SMBs, they respond to the loss or alteration of these areas. There is a general consensus in the literature that data are lacking and/or certain SMBs populations are declining; black rail, king rail, least bittern, seaside sparrow, marsh wren, and purple gallinule are examples (Eddleman et al., 1994; Kroodsma and Verner, 2013; Pickens and Meanley, 2005; Poole et al., 2009; Raftovich et al., 2014; Seamans et al., 2013; Shriver et al., 2008; U.S. Fish and Wildlife Service, 2008; West and Hess, 2002). Black rail, least bittern, limpkin, pied-billed grebe, and seaside sparrow are also listed on the United States Fish and Wildlife Service's Bird Species of Concern 2008 list due to population trends which appear to be declining (U.S. Fish and Wildlife Service, 2008). Factors implicated in the decline of SMBs are loss of wetland habitat and degradation of remaining wetland areas from contaminants and other pollutants (Eddleman et al., 1994; Poole et al., 2009; Rush et al., 2012; Smith and Chow-Fraser, 2010; Tiner, 2013).

Obtaining accurate trends for SMBs is difficult for many reasons. Issues such as inappropriate survey design, low detection rates, and accessibility are central themes. An example of an inappropriate survey method for SMBs are breeding bird surveys. SMBs are not easily detected; this method is designed for species that advertise extensively during the breeding season using both visual cues (brightly colored plumage) and auditory cues (i.e. singing males). Additionally, wetland habitat is often not included in this methodology for logistical reasons (Ribic, 1999; Seamans et al., 2013).

Priority needs therefore center around addressing these issues and data gaps. For example, the development and refinement of a standardized monitoring protocol began in 1999, with the Standardized North American Marsh Bird Monitoring Protocol (Conway, 2011). This protocol is geared specifically for SMBs; it addresses the issue of low detection rates using call-broadcast surveys in marsh habitats. Since many species of SMBs are migratory, coordinated efforts at local, state, and federal levels are necessary to collect appropriate and accessible data (Case and McCool, 2009; Conway and Nadeau, 2006; Seamans et al., 2013; Shriver et al., 2008). Additional needs include improving harvest information for game species, estimating population demographics, understanding migration patterns, monitoring contaminant levels and their effects, and understanding how habitat manipulations or management practices influence SMBs response to the landscape (Case and McCool, 2009; Poole et al., 2009; Rush et al., 2012)

Study Overview

The objectives of this study were developed to address lack of baseline population data, and the effects of contaminants on SMBs. When modeling species abundance, it is necessary to incorporate biologically relevant scales to the organism. For example, two of the focal species for this study are saltmarsh specialists (e.g. clapper rail and seaside sparrow); and as such, face threats from tidal marsh loss, fragmentation, and degradation of marsh (Eddelman and Conway, 1994; Post, 2009). These processes are operating at the landscape scale; however, both species respond to local variables as well, such as patch area or vegetation structure (Rush et al., 2009). Thus, it is necessary to consider multi-scale analyses for these species. Even though several studies have demonstrated the effects of heavy and trace metal contaminants (hereafter HATMC) in other avian species, there is still a dearth of information for HATMC in clapper rails. Specifically, data are lacking for HATMC blood levels. To the best of my knowledge, only one study has quantified HATMC in clapper rail blood samples (Ackerman et al., 2012). Additionally, data are limited regarding hematological measurements such as complete blood counts (hereafter CBC) and biochemistry panels. Due to a diet consisting primarily of invertebrates (Eddelman and Conway, 1994; Rush et al., 2012), the clapper rail is likely the apex predator in terrestrial salt marsh systems, which makes it an ideal candidate to assess the effects of exposure to HATMC (Novak et al., 2006). Lastly, evaluating the prey-base of clapper rails may provide insight into the risk and exposure rates these and other SMBs may experience; in some cases, invertebrate sampling may be a more cost-effective proxy by which to assess contaminant levels (Casazza et al., 2014). The effects of these contaminants on bird health and populations are not known for the Timucuan Ecological & Historic Preserve, located in Jacksonville, Florida (DeVivo et al., 2008).

Study Objectives

In chapter two, I discuss my first objective which was to identify the variables and appropriate scales (i.e. local and landscape) which influence the abundance and distribution of breeding marsh bird species, and to develop Preserve-wide estimates of abundance. In chapter three, I discuss my second objective which was to determine if metal contaminants affect clapper rail health by examining biological samples collected from clapper rail blood and invertebrates (which represent a prey base and potential source of exposure to contaminants) within the Preserve. I expected landscape variables to be significant for breeding SMBs, since other studies have showed this. I also expected that certain local variables (e.g. proportion of *Spartina alterniflora* or *Juncus romerianus*) would be important to species such as seaside sparrow and marsh wren, since both use these plant species as nesting substrate. Ultimately, I expected models to include a range of scales, since avian habitat selection is hierarchical in nature. I developed my own land cover map, and calculated various composition and configuration metrics at varying scales to test these hypotheses. I used single-season N-mixture models to estimate abundance for species with sufficient detections.

In chapter three, I investigate heavy metal and trace contaminants both in clapper rails, and invertebrates, which represent a prey base for clapper rails. Avian studies have shown that adverse health effects are associated with metal levels in birds, but there is a lack of data for blood-metal levels for many species, including clapper rails. I hypothesized that both clapper rails and their prey base would have higher levels of metals in urban regions versus less urban areas. Clapper rails were captured (N=15) and composite-invertebrate samples (N=28) were collected and analyzed for a suite of nine metals using inductively-coupled plasma mass spectrometry.

In chapter four, I summarize my findings from the previous chapters, and discuss limitations and recommendations for improvement. I discuss my approaches to modeling species distribution and abundance, and the use of call-broadcast for marsh bird surveys. I also discuss the interpretation of the metal panels for clapper rails and composite invertebrate samples, and potential implications of these findings.

Study Area

All sampling activities occurred within the administrative boundary of the Timucuan Ecological & Historic Preserve, located in Jacksonville, Florida (Figure 1.1). The total areal extent of the park is approximately 46,000 acres which is jointly managed by the National Park Service, the state of Florida, and the city of Jacksonville (National Park Service, 2006). Coastal wetlands and waterways constitute approximately 75% of this acreage. Estuarine wetlands within the Preserve are dominated by smooth cordgrass (*Spartina alterniflora*) and black needlerush (*Juncus roemerianus*) communities (Brody, 1994; Carlton, 1977). The surrounding uplands of the Preserve are diverse and include habitats such as: coastal strand, shell middens, maritime hammock, pine flatwoods, freshwater wetlands, and pine plantations (Anderson et al., 2005; Elston et al., 2008; Tardona, 1997). The Preserve encompasses portions of both the Nassau river watershed (NRW hereafter) to the north, and the Lower St. Johns river watershed (hereafter LSJW) to the south. Both watersheds face anthropogenic stressors from the surrounding landscape. The NRW is much less urbanized than the LSJW, but it is affected by the presence of silvicultural and agricultural operations, increased residential development, and periodic mercury advisories for fish consumption (Anderson et al., 2005; DeVivo et al., 2008; Florida Department of Environmental Protection, 2007; Gregory et al., 2011). On the other hand, the LSJW is plagued by numerous issues related to high-density development and urbanization: eutrophication (i.e. increased nitrogen and phosphorus), fecal coliform bacteria, increased sedimentation due to surface water runoff, loss of riparian corridors and aquatic habitat due to urban development and dredging, and introduction of contaminants, such as pesticides, herbicides, and heavy metals such as arsenic, lead, mercury and silver (Anderson et al., 2005; Florida, 2016; Maher, 1997; St. Johns River Keeper, 2011). Problems associated with water quality will likely continue, as Jacksonville is ranked as the 12th most populous city in the United States, and population trends are only increasing (U.S. Census Bureau, 2010).

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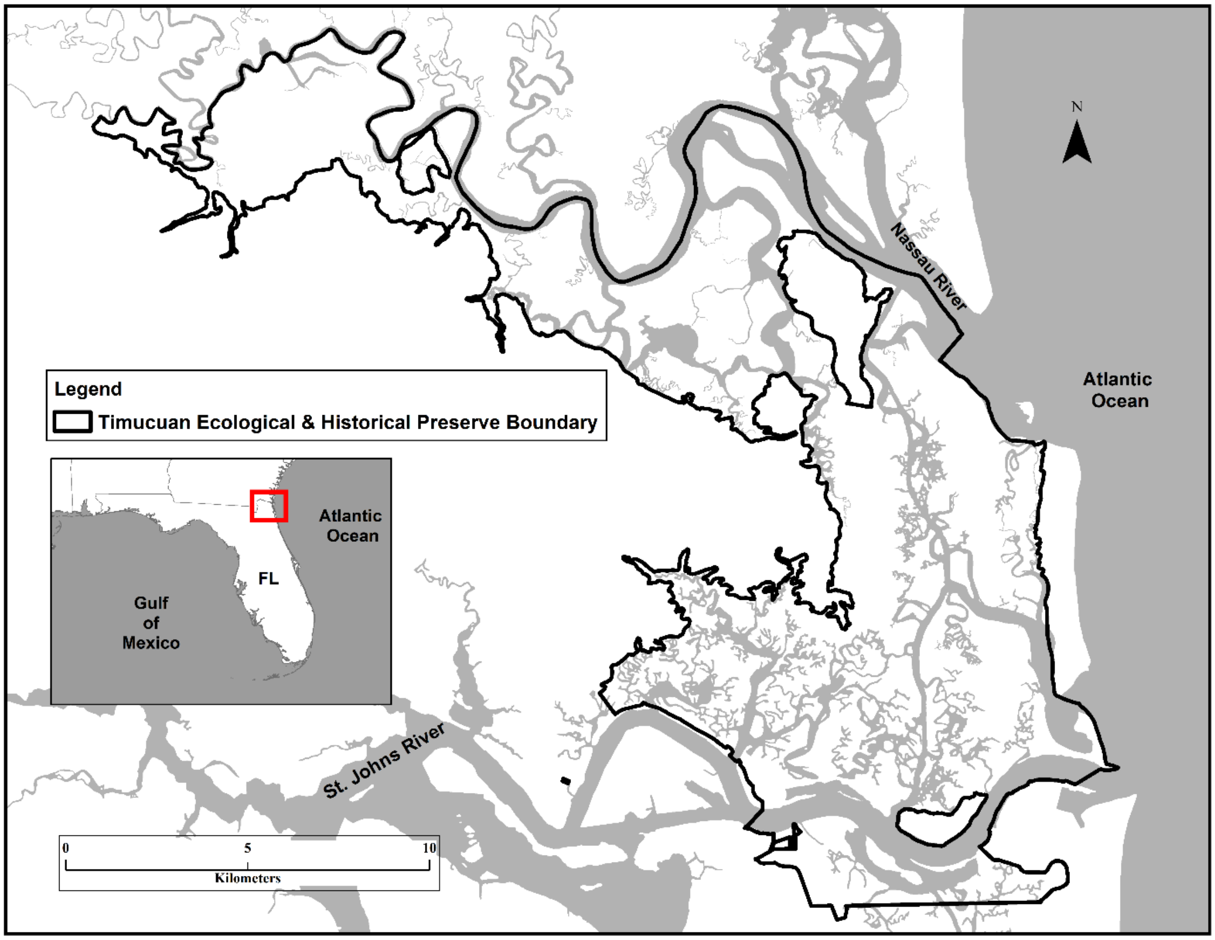

Figure 1.1. Map of the study area, Timucuan Ecological & Historic Preserve, located in Jacksonville, Florida.

CHAPTER 2

VARIABLES AFFECTING THE ABUNDANCE AND DISTRIBUTION OF BREEDING SECRETIVE MARSH BIRDS IN THE TIMUCUAN ECOLOGICAL & HISTORIC PRESERVE, JACKSONVILLE, FLORIDA[1]

[1]Kurimo-Beechuk, E.A., J. Hepinstall-Cymerman, S. Wilde, J. DeVivo, C. Jones. To be submitted to Landscape Ecology

Abstract

The standardized North American marsh bird monitoring protocol was used to conduct avian surveys in Jacksonville, Florida, during two breeding seasons (2015-2016) for eleven species of secretive marsh birds. The protocol includes a passive listening period followed by call-broadcast for target species. Configuration and composition metrics of marsh habitat were calculated at five spatial scales (0.78-7,850 hectares) to investigate the effects of habitat at different scales on marsh bird abundance and distribution. Single-season N-mixture models were used to generate abundance estimates for the four species with sufficient detections for abundance modeling. Overall, results were consistent with other studies, and multi-scale models were supported for all species. There were discrepancies between years for certain models, which may be an artifact of limited detections for some species. The use of call broadcast can introduce variability into counts of birds, which may have been a factor in this analyses.

INDEX WORDS: Abundance, distribution, N-mixture model, multiple scale, Standardized North American Marsh Bird Monitoring Protocol

Introduction

Secretive marsh birds (hereafter SMBs) are a guild of species which exhibit cryptic behavior, are wetland dependent, and poorly understood (Conway, 2011; Eddleman et al., 1994; Ribic, 1999). As the term SMBs implies, these species require wetland habitat for all aspects of their life histories. There is a general consensus in the literature that data are lacking and/or certain SMBs populations are declining (Raftovich et al., 2014; Shriver et al., 2008; U.S. Fish and Wildlife Service, 2008). Several other species appear on the Wildlife Service's Bird Species of Concern 2008 list due to population trends which are concerning (U.S. Fish and Wildlife Service, 2008). There are many factors that contribute to the difficulty in obtaining accurate trends on SMBs. Issues such as inappropriate survey design, low detection rates, and accessibility are central themes. Since wetlands are a requirement for SMBs, they are especially sensitive to the loss or alteration of these areas. When modeling species distributions, it is necessary to incorporate data from spatial scales biologically relevant to the organism; otherwise, important relationships may be overlooked. There are multiple processes occurring at the landscape scale which affect SMBs such as: loss of tidal marsh, fragmentation, and alteration/degradation of marsh habitat (Eddelman and Conway, 1994; Post, 2009). These processes are operating at the landscape scale; however, SMBs respond to local variables as well, such as patch area or vegetation structure (Rush et al., 2009). Therefore, our goal was to incorporate multiple scales into our analyses to identify variables important for breeding SMBs.

Coastal wetlands are dynamic entities which are shaped by numerous abiotic and biotic processes. Hydrologic regime, salinity, nutrient availability and cycling, climate, human-caused disturbances, and physical disturbances are abiotic processes which influence the patterns of the landscape, such as the resulting vegetation and animal communities. Biotic processes include interspecific competition and predation (Tiner, 2013). Patterns and processes work synergistically to create the spatial heterogeneity that is observed on the landscape. Landscapes by definition are heterogeneous areas, and the analysis of their components are scale dependent. Selection of the appropriate scale is imperative to understanding the spatial heterogeneity in dynamic systems such as coastal wetlands, because the structure or ecological function of the landscape may vary depending on the scale under examination (Turner, 1989).

Avian response to the landscape is recognized as occurring as a hierarchical process; Johnson (1980) delineated four distinct orders or scales of selection: first-order (geographic range), second-order (home range), third-order (use of habitat components within a home range), and fourth-order (micro-habitats). For birds, hierarchical selection occurs at the landscape scale first; birds then cue in on variables which are important to their life cycle at the time. For example, corncrake (*Crex crex*) are an area-sensitive species which are thought to respond first to the presence of river corridors in the landscape matrix, and then select habitat based upon local-scale characteristics (Schipper et al., 2011). Selection of specific habitat within a home range occurs based upon the need for food, shelter, and breeding components (Johnson, 1980; Lack, 1937; Wiens, 1989).

Local-scale variables, or those which occur within an organism's home range, include food availability, vegetation structure, and other microhabitat characteristics, such as available nesting and roosting sites (Johnson, 1980). Depending on the species, the apparent importance of local-scale variables can vary (Crozier and Niemi, 2003; Kirk et al., 2001; Moffett et al., 2014; Monfils et al., 2012; Schindler et al., 2013; Spautz et al., 2006; Valente, 2009). For example, clapper rails during the breeding season constrict their home ranges in response to local fiddler crab density, a common prey source (Rush et al., 2010). In contrast, Monfils et al. (2012), found that models containing landscape variables ranked higher than models containing local variables for several SMB species. Another possible explanation for the variation in bird abundance could be the quality of available habitat or context of the surrounding landscape, such as for clapper rails, which have been found to respond negatively to road density at the landscape scale (Shriver et al., 2004).

The response of SMBs to landscape variables can elucidate the effects of area-sensitive relationships, habitat fragmentation, and context of landscape quality in terms of the degree or type of anthropogenic disturbances (DeLuca et al., 2004; Quesnelle et al., 2013; Shriver et al., 2004; Smith and Chow-Fraser, 2010). Anthropogenic influences such as agricultural, silvicultural, or urban development are often associated with negative effects on avian communities, particularly obligate marsh birds (DeLuca et al., 2004; Forcey et al., 2007; Kelly et al., 2008; Kennedy et al., 2010; Kuhn et al., 2011;

Melles et al., 2003; Rodewald and Yahner, 2001; Shriver et al., 2004; Smith and Chow-Fraser, 2010; Tozer et al., 2010; Webb et al., 2010). Human-induced disturbance can degrade habitat in the following manners: introduction of contaminants (Tiner, 2013), decreased resource availability, and increased edge effects (DeLuca et al., 2004; Kennedy et al., 2010), which can facilitate predation and introduction of generalist species, causing inter-species competition (Saab, 1999). Numerous studies show the importance of utilizing both local and landscape-scale variables in modeling avian distribution and abundance (Monfils et al., 2012; Spautz et al., 2006; Tozer et al., 2010). Modeling a species' response to the landscape at multiple scales is more accurate and biologically relevant to how an organism perceives and interacts with its environment.

Regardless of the scale considered, there is a common theme to the types of variables that are important for breeding SMBs. Vegetation structure, competition, and productivity are known to affect distribution of bird communities (Cody, 1981; Murkin et al., 1997). A review of wetland use identified additional categories as influential to wetland bird communities: hydrologic regime (i.e. water depth and fluctuation), vegetation communities, food resources, and various wetland metrics which measure patterns such as connectivity, area, and topography (Ma et al., 2009). Both composition and configuration metrics are used to model the patterns of the landscape which aid in predicting species' abundance and distribution. Composition metrics such as richness, evenness, and proportional abundance of class type have traditionally been the focus in wetland bird studies (Bookhout and Stenzel, 1987; Craig and Beal, 1992; Fitzsimmons et al., 2012; Moffett et al., 2014; Naugle et al., 1999; Quesnelle et al., 2013; Roach, 2015; Stralberg et al., 2010; Webb et al., 2010). On the other hand, the use of configuration metrics are becoming more frequent, and several studies have demonstrated their importance in landscape ecology studies (Cushman and Mcgarigal, 2004; Kelly et al., 2008; Parrish and Hepinstall-Cymerman, 2011; Rehm and Baldassarre, 2007a). Configuration metrics are those that are spatially explicit, and include variables such as connectivity, edge density, patch density, interspersion, juxtaposition, and patch-shape complexity. Configuration metrics quantify the patterns on the landscape which may explain the apparent high densities of breeding SMBs in certain areas (Moffett et al., 2014; Rehm and Baldassarre, 2007a). It is likely that SMBs are responding at multiple spatial and temporal scales depending on the season and specific processes under consideration.

The response of SMBs to the landscape also has management and conservation implications. The study site for this project, the Timucuan Ecological & Historic Preserve, Jacksonville, Florida (discussed further below), is surrounded by various industrial, agricultural, and urban operations. Establishing a baseline assessment of SMB populations within the Preserve will help managers and future researchers understand what types of variables influence SMB communities in this region. In turn, these data can guide management activities for existing areas within the Preserve, but also new land acquisitions as well. Lastly, establishing baseline information for these birds fits into the larger context of their management: other entities (e.g., governmental agencies, working groups, non-governmental organizations) can also use this information to address data gaps for a particular species.

Study Objectives

The objectives of this study were developed to address lack of baseline population data for SMBs. Specifically, the aim was to 1) identify the variables and appropriate scales (i.e. local and landscape) which influence the abundance and distribution of breeding marsh bird species, and 2) develop Preserve-wide estimates of abundance and distribution for breeding SMBs.

Study Area

All sampling activities occurred within the administrative boundary of the Timucuan Ecological & Historic Preserve, located in Jacksonville, Florida (Figure 1.1). The total areal extent of the park is approximately 46,000 acres which is jointly managed by the National Park Service, the state of Florida, and the city of Jacksonville (National Park Service, 2006). Coastal wetlands and waterways constitute approximately 75% of this acreage. Estuarine wetlands within the Preserve are dominated by smooth cordgrass (*Spartina alterniflora*) and black needlerush (*Juncus roemerianus*) communities (Brody, 1994; Carlton, 1977). The surrounding uplands of the Preserve are diverse and include habitats such as: coastal strand, shell middens, maritime hammock, pine flatwoods, freshwater wetlands, and pine plantations (Anderson et al., 2005; Elston et al., 2008; Tardona, 1997). The Preserve encompasses portions of both the Nassau river watershed (NW hereafter) to the north, and the Lower St. Johns river watershed (hereafter LSJW) to the south. Both watersheds face anthropogenic stressors from the surrounding landscape. The NW is much less urbanized than the LSJW, but it is affected by the presence of silvicultural and agricultural operations, increased residential development, and periodic mercury advisories for fish consumption (Anderson et al., 2005; DeVivo et al., 2008; Florida Department of Environmental Protection, 2007; Gregory et al., 2011). On the other hand, the LSJW is plagued by numerous issues related to high-density development and urbanization: eutrophication (i.e. increased nitrogen and phosphorus), fecal coliform bacteria, increased sedimentation due to surface water runoff, loss of riparian corridors and aquatic habitat due to urban development and dredging, and introduction of contaminants, such as pesticides, herbicides, and heavy metals such as arsenic, lead, mercury and silver (Anderson et al., 2005; Maher, 1997; St. Johns River Keeper, 2011; University of North Florida, 2016).

Methods

Study design and site selection

Avian sample locations were chosen based on a 400-meter x 400-meter grid within the administrative boundary of the Preserve. Grid spacing was consistent with recommendations from the Standardized North American Marsh Bird Monitoring Protocol for new survey areas (Conway, 2011). All surveys in 2015 were conducted by jon boat with a motor at the emergent marsh-water interface. If a sample location did not fall at this interface, (i.e. in the middle of the channel or non-marsh habitat) the closest suitable location to the original point was chosen. This approach allowed for substitution of sample locations based on access problems (oyster beds, shallow waters, falling tides, sand bars, etc.). For the 2016 field season, all surveys were conducted by canoe with a trolling motor. A canoe with a trolling motor setup was used because a jon boat was not available. The same 400-meter x 400-meter grid was used to select potential sample locations, but sample locations for the 2016 season were a completely different set from those sampled in 2015, due to the type of boat used (i.e. canoe was not taken in to deep water channels for safety reasons). To account for the difference in sample locations across years, each year was analyzed separately, and pooled together with a 'year' effect. The complete description of the sample location selection process is located in Appendix A.

Fixed-radius point counts

Fixed-radius point counts (truncated at 200 meters) were conducted at a minimum of 400 meters apart for the following target species: American coot (*Fulica americana*), black rail (*Laterallus jamaicensis*), clapper rail (*Rallus crepitans*), common gallinule (*Gallinula galeata*), king rail (*Rallus elegans*), least bittern (*Ixobrychus exilis*), limpkin (*Aramus guarauna*), marsh wren (*Cistothorus palustris*), pied-billed grebe (*Podilymbus podiceps*), purple gallinule (*Porphyrio martinicus*), and seaside sparrow (*Ammodramus maritimus*). This method was chosen to ensure independence of detections between sample locations. Surveys were not conducted in inclement weather, or if wind speeds were greater than 10 miles per hour. All surveys were conducted by boat (jon or canoe) at the emergent vegetation-water interface, starting one-half hour before sunrise until two-hours post sunrise. Routes were established by choosing points such that the survey contained as many points as possible in a morning. Once routes were established, every effort was made to visit each route once within each of the recommended survey intervals (Figure 2.1). Due to the low detection rates of SMBs, the territorial calls of focal species were broadcast after a five-minute passive listening period to elicit higher rates of detection (Conway, 2011). Broadcast calls were used for the following species, upon the recommendations of Dr. Courtney Conway: black rail, clapper rail, king rail, least bittern, purple gallinule, and limpkin. The passive period followed by the broadcast call series translated to an eleven-minute survey. Detections of individuals of a target species were recorded in one-minute intervals (i.e. 0-1 minutes, 1-2 minutes, until the end of the survey). Detections were classified as auditory, visual, or both. If the detection was an auditory detection, the type of call was recorded. Distance and bearing to all detected individuals were recorded using a Bushnell laser rangefinder and compass, respectively. Due to the lack of vertical structure in the marsh and the fact that detections were usually auditory, distance calculations using the range finder often were not feasible. Therefore, the type of distance estimation was also recorded (i.e.

range finder with visual detection, range finder with auditory detection, and none). Detections of target species outside of the survey period were also recorded, and noted as such.

Survey and site-specific measurements

All survey and site-specific measurements were collected based on recommendations from the SNAMBMP, 2011 (Conway, 2011). Prior to the commencement of a survey, the following measurements were collected: time, cloud cover, air temperature, wind speed, ambient noise, water depth, salinity, water temperature, pH, specific conductance, dissolved oxygen, and tidal stage. Site-specific habitat characteristics were recorded for all sample locations when feasible. Percent vegetation cover within a 50-m radius, dominant and co-dominant vegetation cover, mean height of dominant vegetation, vegetation density, and elevation were recorded in the field. Additionally, distance to uplands, roads, large channels (i.e. > 4 foot water depth), and distance to mudflats using a laser rangefinder when applicable were also recorded. Photographs at each cardinal direction were taken to document the features at each sample location.

Landscape analysis and generation of predictor variables

Land cover data were obtained from the Florida Fish and Wildlife Conservation Commission and Florida Natural Areas Inventory Cooperative Land Cover version 3.1, 2014 (10-meter pixel). These land cover data were reclassified to the following six classes: marsh, water, urban, agriculture, non-forest natural areas, and forested natural areas. Road and water vector layers from the National Park Service were converted to raster format and overlaid on top of the reclassified raster layer to refine the final layer used in this analysis (Figure 2.2). A five-kilometer buffer was placed around the study area so boundary effects were mitigated. To investigate the effects of multiple scales on SMB abundance and distribution, configuration and composition metrics were calculated for selected classes at multiple scales (0.78, 3.14, 50.24, 706.50, and 7,850 hectares) with an eight-cell rule using Fragstats version 4.0 (McGarigal, 2015). The resulting raster layers from the Fragstats and ArcGIS analyses were used for predicting abundance ($\hat{N}$) at sample locations, and for the Preserve.

Site differences between years

Due to the differences in sample locations between years, the approach of analyzing each year separately was taken so that assumptions of a closed population were met, and to determine if site variables had the same effect between years. A decision to pool data and include a 'year' effect was made to determine if pooling the data enhanced the ability of candidate models to detect effects of site covariates. Generally, habitat variables were consistent amongst years, but caution should be used in the interpretation of abundance estimates for each separate-year analysis, since predictions may be extrapolating beyond the range of the data for certain areas within the Preserve. For this reason, predictions are presented with lower and upper confidence intervals, and standard errors.

Abundance model development

A priori candidate models were developed for the 2015, 2016, and pooled 2015-2016 seasons for species with sufficient detections after preliminary exploratory data analysis and reviewing current literature. Choice of scales were based upon a literature review for other SMBs species, and other wetland birds (Table 2.1). Models were developed using variables which were hypothesized as biologically relevant (Table 2.2) for breeding SMBs in this area; refer to Appendix B, Tables B.1-B.12 for the complete list of models developed for each species. Abundance-level covariates were the same across years for each model, but to account for year to year differences between sample locations, detection-level covariates varied between years. Data for both 2015 and 2016 seasons were analyzed separately, and pooled using a YEAR effect in the detection model for pooled data. A Pearson's r correlation coefficient matrix was constructed for detection-level and abundance-level covariates prior to inclusion in candidate models, to avoid multicollinearity. Highly correlated variables >|0.6| were not included within the same model.

Since surveys were conducted at the emergent vegetation-water interface, the amount of land area surveyed varied between sample locations (i.e. area of emergent vegetation within a 200-meter radius around a sample location). One method to account for unequal survey effort is to include an offset (Kery and Royle, 2016). Including an offset for the area surveyed is analogous to taking the log of the area for that site, and assuming the coefficient of this area parameter has a value equal to one. This essentially is modeling a proportional increase in the expected count of individuals, as the area surveyed increases. To account for this unequal survey effort, the effects of including an offset of the log of area surveyed and including the log of area surveyed as a parameter were investigated by examining the coefficients of models which included modeling the area as an offset, and as a parameter. Since the estimated coefficient of the log of area surveyed was different than one, indicating that expected counts are dependent on the amount of area surveyed, a decision was made to include it as a parameter in the ecological process model to account for unequal survey effort (Kery and Royle, 2016). The **pcount** function in package unmarked in the R statistical environment was used to generate abundance estimates (Fiske and Chandler, 2011). The **pcount** function utilizes the single-season, N-mixture models developed by Royle (2004). N-mixture models are a hierarchical class of models that are composed of two separate sub-models: one model which describes the detection process, and another sub-model which describes the state or ecological process of interest, e.g. abundance (Royle, 2004). What makes this class of models hierarchical is the nested structure of the random variables (see below) (Kery, 2013). N-mixture models as a method to estimate population size are an attractive alternative to other methods such as capture-recapture methods, which are often difficult in terms of logistics and feasibility. N-mixture models require data with either spatial replication or temporal replication (i.e. multiple visits to a site) in order to inform the detection model (Royle, 2004). The general form of the N-mixture model for count data is presented below:

$$N_i \sim \text{Poisson}(\lambda_i) \rightarrow \text{Ecological process model}$$

$$y_{ij} \sim \text{Binomial}(N_i, p_{ij}) \rightarrow \text{Detection process model}$$

where N_i represents the latent (i.e. partially or totally unobserved) random variable of local abundance at $site_i$; λ_i represents the mean of this local abundance, following a Poisson distribution. y_{ij} represents observations (i.e. counts of individuals) indexed by $site_i$, $survey_j$, given N_i, with a probability of detection p, which is also indexed by $site_i$, $survey_j$, but the same across individuals (Kery and Schaub, 2012; Royle, 2004). For data sets that have excess zero counts or more variability than would normally occur under a Poisson distribution, both the negative binomial and zero-inflated Poisson distributions are alternatives.

The negative binomial distribution is similar to the Poisson, but has an additional dispersion parameter, which allows for the expression of more variability about the mean parameter (Kery and Royle, 2016). A zero-inflated Poisson distribution also accommodates excess zeroes through a binary distribution and a normal Poisson distribution (Kery and Royle, 2016). Both negative binomial and zero-inflated Poisson distribution models were considered for species modeled as 'KICL' (defined below).

Model selection and assessment

Model selection was performed for each candidate set of models using Aikaike Information Criterion for small sample size (AICc) (Anderson and Burnham, 2002). Models with a Δ AICc <2 were deemed competitive, and predictions were based on sets of these models (Anderson and Burnham, 2002). In cases where it was clear that a model outranked other models in terms of AICc value, that model was selected for making predictions (Appendix C, Tables C.1-C.12). Due to the unequal replication of visits to several sample locations, there were multiple missing values for observational covariates. These missing values were imputed using the mean for that sample location, so that AICc model selection processes could be used. Goodness of fit was examined for top-ranking models by performing a parameteric bootstrapping procedure (N=1,000 simulations) using the **parboot** function in R. This function calculates residual sum of squares, chi-squared (X^2), and Freeman-Tukey chi-squared goodness-of-fit, and root mean square error fit statistics. Over or under dispersion of top models was assessed by calculating a c-hat value, which is the ratio of observed chi-squared (X^2) statistic to the expected chi-squared (X^2) statistic (Kery and Royle, 2016). Results of the goodness-of-fit assessment for abundance models are located in Appendix D, Tables D.1-D.4.

Local site abundance and Preserve predictions

A parametric bootstrapping procedure (N=1,000 simulations) was used to estimate local site abundance ($\hat{N}$) and by summing the best unbiased predictor for the random effects across all sample locations and generating 95 % confidence intervals using the top model (s) for each species for each year separately. Preserve-wide abundance predictions ($\hat{N}$) and species distribution maps were created using covariate raster layers which were resampled to a 354-meter pixel size (i.e. the amount of marsh area analogous to a 200-meter radius, or the effective survey area) using a bilinear function in ArcMap. Species distribution maps and predictions of total abundance within the Preserve were created with top models. In the case where spatial data were not available for the entire Preserve (e.g. salinity), the species distribution maps were created using the next best-ranked model. Avian survey summary figures and species predictions are located in Appendix E, Figures E.1-E.24.

Results

Data summary

In 2015, 39 sample locations were surveyed, and in 2016, 51 sample locations were surveyed (Figure 2.3). In 2015 and 2016, there were 2 detections in each year for least bitterns, and both years only had one detection each for common gallinules. There was a single black rail detection, and this occurred in 2015 during the black rail interval of the survey. Least bitterns overall did not appear to be influenced by call-broadcast. There were also detections of soras (*Porzana carolina*) in both years, and Virginia rails (*Rallus limicola*) in 2016. For both years, differentiation of clapper rails from king rails was not always possible; as such, birds which could not be readily identified as either clapper rail or king rail were modelled as ‘KICL’, to account for uncertainty.

Clapper rail

There was a total of 390 detections across 31 sample locations for clapper rails in 2015, 447 detections across 42 sample locations in 2016, and 837 detections across 73 sample locations in the pooled data set. In 2015, clapper rail detections increased as the season progressed, but detections in 2016 and the pooled data set did not follow the same trend and peaked during the second window. The use of call-broadcast increased detections for clapper rails in all years. Detection covariates were different for each year; in 2015 and the pooled data set, Julian date had a positive effect on detection, while in 2016, air temperature had a positive effect on detection probability. The 95% confidence intervals for all other detection covariates included zero. Patch density of marsh habitat within 7,850 ha had a positive effect on clapper rail abundance in both 2015 and the pooled data set. In 2016, the percentage of agriculture had a strong negative effect. The proportion of *Spartina alterniflora* within 0.785 ha had a positive effect on abundance in the pooled data set. The 95% confidence intervals for all other abundance covariates included zero (Table 2.3). Local site abundance was N̂ = 288.05, 95% [280, 480] in 2015, N̂ = 811, 95% [434, 2407] in 2016, and N̂ = 634, 95% [536, 798] for the pooled data set. Predicted total abundance within the Preserve in 2015 was N̂ = 49,035 birds, 95% [40,908, 107,417], N̂ = 72,086 birds, 95% [33,085, 315,457] in 2016, and N̂ = 53,464 birds, 95% [44,028, 89,905] for the pooled data set. The upper limits of these confidence intervals represent unbounded limits (i.e. they have not been censored according to biologically feasible limits).

KICL

Species modeled as 'KICL' had a total of 88 detections across 11 sample locations for the 2015 season, 92 detections across 13 sample locations for the 2016 season, and 180 detections across 24 sample locations for the pooled data set. In 2015, king rail detections increased throughout the season, while KICL had too few detections to discern a trend. In 2016, both king rail and KICL detections declined over the course of the breeding season. In the pooled data set, king rail detections were constant, while KICL declined through the season. Wind had a negative effect on detection probability for the 2015 data, but the 95% confidence interval overlapped zero in one model. Julian date negatively impacted detection probability in the 2016 data set. The 95% confidence intervals for all other detection covariates across years included zero. The effect of call-broad cast was similar across years, and in general, increased detections. In 2015, the effects of mean salinity and patch density of marsh within 7,850 ha were negative on KICL abundance. Both the percentage of the surrounding landscape consisting of agriculture and percentage of marsh habitat within 7,850 ha had a positive effect on KICL abundance in 2016, and patch density of marsh within 706.50 ha had a positive effect on KICL abundance in the pooled data set. The 95% confidence intervals for all other abundance covariates included zero (Table 2.4). Site abundance was calculated separately for the top two models in 2015, and estimated abundance was N̂ = 58.9, 95% [40, 373], (fm1), and N̂ = 58.4, 95% [39, 199], (fm5), respectively. In 2016, site abundance was N̂ = 953, 95% [67, 992]. Local site abundance was calculated separately for the top two models in the pooled data set, and estimated N̂ = 213, 95% [120, 509], (fm6ZP), and N̂ = 216, 95% [100, 564], (fm8ZP), respectively. Preserve-wide predictions of abundance for 2015 were made under one model since salinity data were not available for the entire Preserve. Predicted abundance for this model was $\hat{N}$ = 83,753 birds, 95% [38,942, 300,000]. In 2016, abundance was $\hat{N}$ = 1,050,052 birds, 95% [238,009, 8^9]. For the pooled data set, predictions were $\hat{N}$ = 72,503 birds, 95% [65,604, 4.0^5], (fm6ZP), and $\hat{N}$ = 71,065 birds, 95% [61,841, 414,291], (fm8ZP), respectively. As with clapper rails, the upper limits of these confidence intervals represent unbounded limits (i.e. they have not been censored according to biologically feasible limits).

Marsh wren

Marsh wrens had 168 detections across 36 sample locations in 2015, 103 detections across 37 sample locations in 2016, and 271 detections across 73 sample locations for the pooled data set. Detections by survey window varied across years; in 2015 and the pooled data set, detections peaked during the second survey window, while in 2016, detections declined throughout the season. Background noise had a negative effect on detection probability in all three 2015 models, as did Julian date for the single model in 2016. In the pooled data set, air temperature had a negative effect on detection probability for two of the three models. The 95% confidence intervals for all other detection covariates included zero. Increasing distance to forested natural habitat had a positive effect on marsh wren abundance in all models. In 2016, the proportion of *Spartina alterniflora* within 0.785 ha had a negative effect on marsh wren abundance. The 95% confidence intervals for all other abundance covariates included zero (Table 2.5). Local site abundance was calculated separately for the three models in 2015: $\hat{N}$ = 1,052, 95% [219, 2,023], (fm9), $\hat{N}$ = 798, 95% [207, 1,784], (fm1), and $\hat{N}$ = 631, 95% [191, 1,800], (fm6), respectively. Local site abundance was $\hat{N}$ = 383, 95% [165, 1384] in 2016. In the pooled data set, $\hat{N}$ = 431, 95% [292, 1,745], (fm6), $\hat{N}$ = 423, 95% [281, 1265], (fm9), and $\hat{N}$ = 425, 95% [369, 1512], (fm1), in top models. Abundance for the Preserve-wide predictions in 2015 was estimated for three models (fm1, fm6, fm9), and was $\hat{N}$ =39,680, 95% [37,064, 47,124], $\hat{N}$ =39,407, 95% [36,696, 47,212], and $\hat{N}$ =39,951, 95% [36,944, 48,435]. Predictions for the pooled data set were made under the same models as 2015; and Preserve-wide abundance was $\hat{N}$ =82,589, 95% [51,264, 305,685], $\hat{N}$ =83,732 95% [52,111, 3.0^5], and $\hat{N}$

=84,690, 95% [53,111, 3.0^5]. For the 2016 data set, predictions for the Preserve were $\hat{N}$ =112,666, 95% [39,605, 1.0^7]. Again, the upper limits of these confidence intervals represent unbounded limits (i.e. they have not been censored according to biologically feasible limits).

Seaside sparrow

Seaside sparrows had 91 detections across 23 sample locations in 2015, 20 detections across 8 sample locations in 2016, and 111 detections across 31 sample locations for the pooled data set. Detections peaked in the second survey window for 2015, declined over the breeding season in 2016, and remained constant in the pooled data set. Wind speed and noise had a negative effect on detection probability in all three models; however; the confidence interval for noise overlapped zero in one model (Table 2.6). Julian date had a negative effect on detection probability in 2016, and 95 % confidence intervals included zero for all other detection covariates. In 2015, mean salinity had a positive effect on abundance. In 2015 and 2016, the percentage of the landscape comprised of forest within 7,850 ha was negatively associated with seaside sparrow abundance in multiple models. In 2016, increasing distance to urban features was positively associated with abundance. For the pooled data set, the percentage of the landscape comprised of non-forested habitat within 7,850 ha was negatively associated with seaside sparrow abundance, and proportion of *Spartina alterniflora* within 3.14 ha was positively associated with seaside sparrow abundance (Table 2.6). Local site abundance in 2015 was calculated separately for each model (fm6, fm1, fm4) and were similar: $\hat{N}$ = 70.7, 95% [48, 139], $\hat{N}$ = 64.3, 95% [44, 111], and $\hat{N}$ = 69.4, 95% [46, 134]. In 2016, local site abundance was $\hat{N}$ = 37, 95% [14, 728], and in the pooled data set, local site abundance was $\hat{N}$ = 86.7, 95% [80, 130]. Since salinity data were not available for the entire Preserve, predictions are based on the remaining models. In 2015, Preserve predictions of abundance were $\hat{N}$ =36,939 95% [28,819, 62,534], (fm4), and $\hat{N}$ =37,946, 95% [30,265, 64,533], (fm6). Preserve predictions in 2016 were $\hat{N}$ =8,508,712, 95% [40,363, 5.8^{21}]. In the pooled data set, predictions were $\hat{N}$ =155,366, 95% [41,708, 1,544,502]. As was the case with the previously listed species, the upper limits of these confidence intervals represent unbounded limits.

Discussion

General considerations

Only four of the eleven target species had a sufficient number of detections which allowed abundance modeling. This is likely a function of the habitat within the Preserve; most of my study sites were located within estuarine wetlands. Species such as American coot, common gallinule, least bittern, limpkin, purple gallinule, and pied-billed grebe are typically not found in these types of areas, since these species prefer either fresh water wetlands, or ponded areas (Bannor and Kiviat, 2002; Brisbin and Mowbray, 2002; Bryan, 2002; Muller and Storer, 1999; Poole et al., 2009; West and Hess, 2002). In the same vein, clapper rails were the most frequently and widely detected species in both years.

Clapper rail

Expected detection probability declined with increasing minutes after sunrise, while Julian date was positively associated with detection probability, but 95 % confidence intervals included zero for both parameters. These findings are consistent with other studies, as detections for marsh birds generally decline throughout the morning (Conway and Gibbs, 2001); however, one study demonstrated a negative effect of date on clapper rail detection probability (Hunter et al., 2017). Air temperature and noise were associated with clapper rail detection probability in 2016. Air temperature had a positive effect on detection probability, while noise had a negative effect. It is likely for air temperature to be correlated with Julian date, but this was not the case for data collected in 2016. Sample locations for the 2015 season were restricted to more open channels and deeper waters, while locations in 2016 were much closer to terrestrial locations, where background noise may have had more of an influence.

Patch density of marsh within 7,850 ha was positively associated with clapper rail abundance in the 2015 and pooled data sets. As patch density increases on the landscape, the appearance of marsh habitat becomes more fragmented. Higher patch density of marsh may represent increased foraging and nesting opportunities (i.e more patches) in closer proximity to emergent vegetation, which provides protection from predators. Percentage of *Spartina alterniflora* within 0.785 ha was also in the top 2015 model. This parameter had a positive effect on clapper rail abundance, and this is consistent with the fact that clapper rails use *Spartina alterniflora* for nesting habitat (Gaines et al., 2003; Leggett, 2014; Rush et al., 2012), and vegetation composition (species) is a predictor of rail abundance (Stralberg et al., 2010). In 2016, edge density of marsh habitat within 706.50 ha and percentage of the landscape composed of agriculture within 7,850 ha were variables present in the top model. Edge density is a variable that other studies have tested as a predictor of bird abundance; but the effects can vary across species. Some studies have found positive associations of edge density and bird abundance (Crozier and Niemi, 2003; Monfils et al., 2012; Rehm and Baldassarre, 2007a; Rush et al., 2010); while other studies have found no effect (Monfils et al., 2012; Roach, 2015). Rehm and Baldassarre 2007 found that increased interspersion (quantified by edge density) was positively associated with breeding marsh bird density, and this was likely due to the increased nesting and foraging habitat associated with edge habitats. Clapper rails select and adjust home ranges in response to available foraging areas/prey availability (Ricketts, 2011; Rush et al., 2010), and increased edge in tidal environments is likely a proxy for these variables. In our study, edge density had a negative effect, but the 95 % confidence interval did overlap zero. A possible explanation for this finding is the use of edge habitats by rails may depend on tidal stage (Rush et al., 2010), with use of edge habitat decreasing with tidal amplitude and a similar finding was documented by Hunter et al., 2017. The percentage of landscape composed of agriculture within 7,850 ha was negatively correlated with clapper rail abundance. The context of the landscape surrounding wetlands can impact marsh birds (Crewe and Timmermans, 2005; DeLuca et al., 2004; Smith and Chow-Fraser, 2010); Quesnelle et al. 2013 found that marsh-obligate species were more sensitive and responded negatively to anthropogenic disturbances around wetlands than marsh-generalist species. The same trend has also been documented in other bird species (Melles et al., 2003; Rodewald and Yahner, 2001). Model fit was variable across years, with the best fitting model occurring in 2015. Model fit was adequate for 2016, but not for the pooled data set. A possible reason is that there was difficulty in classifying birds as either king rails or clapper rails during field surveys. This may have masked or obscured relationships with certain covariates, and contributed to poor model fit. Additionally, sample locations were not the same between years, and site-specific characteristics may be driving the different responses to certain covariates.

KICL

For species modeled as KICL, wind speed was an important detection-level covariate in the 2015 analysis. Wind speed negatively impacted KICL detections. Wind speed may decrease the ability of an observer to detect birds, and/or vocalization rates may be lower during windy periods (Conway and Gibbs, 2011); but not all studies demonstrated this (Alexander, 2011). For 2016, Julian date was associated negatively with detection probability. As mentioned previously, the effect of Julian date on detection probability can vary by species (Alexander, 2011; Conway and Gibbs, 2011; Harms and Dinsmore, 2014; Leggett, 2014; Rehm and Baldassarre, 2007b); a similar trend to this study was noted in king rails in Louisiana, but detections were rare, so this may not be a generalizable response (Valente, 2009). It is interesting to note that clapper rails in this study had the opposite response to Julian date.

Mean salinity was negatively associated with KICL abundance in 2015, which is not surprising since king rails are typically found in freshwater environments (Pickens and Meanley, 2005). However, salinity is not always an influential variable on occupancy or abundance (Rogers, 2011). Additionally, populations of both king rails and clapper rails can occur sympatrically in brackish marshes (Glisson et al., 2015), and thus, can exhibit varying responses to salinity gradients (Hunter et al., 2017). Patch density of marsh within 7,850 ha was negatively associated with KICL abundance in 2015, while patch density of marsh within 706.50 ha was positively associated with KICL abundance in the pooled data set. A possible explanation for the variable response to patch density is the difference in scale; ecological relationships are dependent on the scale, since interactions and processes change as scale changes. Both percentage of agriculture within 7,850 ha and percentage of marsh habitat within 7,850 ha were positively associated with KICL abundance in 2016. King rails may be an area-sensitive species; the results from other studies suggest they select areas which have greater coverage of emergent vegetation (Budd, 2007; Valente, 2009). Similar results were demonstrated by Valente, 2009, who found that king rails would nest in rice fields adjacent to marshes. Both edge density and patch density of marsh habitat within 706.50 ha were positively associated with KICL abundance in the pooled data set, which may be associated with greater resource availability. Model fit was mostly adequate for the KICL analyses, with the exception of the

2015 models, which also were overdispersed. As stated before, it was not always possible to distinguish king and clapper rails in the field, so a decision was made to combine either king rail or KICL detections into a generic category of KICL. It is entirely plausible that birds in this category are a mixture of both king and clapper rails. If this is truly the case, then this could explain discrepancies amongst models, model fit, and years for both species. Additionally, the number of detections for KICL were not large, and KICL were only detected at 24 sample locations.

Marsh wren

Background noise in had a negative effect on marsh wren detection probability in all 2015 models. In 2016, Julian date and air temperature were negatively associated with detection probabilities in 2016 and pooled data sets, respectively. Again, the results of these studies are consistent with other marsh bird species responses to these variables (Conway and Gibbs, 2001; Conway and Gibbs, 2011). The negative response to Julian date may be related to breeding or nesting activities. Reasons for variation in the best-supported detection covariates amongst years is potentially attributable to site differences.

For marsh wrens in this study, there was some degree of consistency between top models and types of abundance-level covariates across years. Increasing Euclidean distance to forested habitat was positively associated with marsh wren abundance in all models. Forest cover may represent a source for terrestrial predators, and this may be a reason that marsh wrens avoid these areas. Other studies have demonstrated similar findings, and documented negative responses of marsh wrens to tree or non-marsh cover in the landscape (Kirk et al., 2001; Quesnelle et al., 2013; Spautz et al., 2006). Landscape context seems to be an important factor to marsh wrens; marsh wrens respond to vegetation composition and structure at multiple scales (Quesnelle et al., 2013; Shriver et al., 2004). Marsh wren abundance varied in response to mean patch area of marsh within 50.24 ha. Results from other studies have found that marsh wren occurrence generally increases with greater marsh coverage (Quesnelle et al., 2013; Tozer et al., 2010), so marsh wrens in this study may be responding to vegetation composition versus areal extent of emergent vegetation. It is entirely possible that marsh wrens do not respond to marsh area at this scale; several studies have found that marsh wrens are responsive at much larger scales than what was measured in these models (Quesnelle et al., 2013; Spautz et al., 2006; Tozer et al., 2010). Both the proportion of *Juncus romerianus* and *Spartina alterniflora* were included in several top models for marsh wrens, although these results were not significant. In general, marsh wren response to *Spartina alterniflora* and *Juncus romerianus* was variable. Marsh wrens do exhibit diversity in nesting habitats, which may explain the variable response to both *Spartina alterniflora* and *Juncus romerianus* (Kroodsma and Verner, 2013). Model fit for marsh wrens was acceptable for the 2015 and 2016 analyses; however, the pooled data sets performed poorly. Another point to consider is that both marsh wrens and seaside sparrows (discussed in the next section) were not initial target species. The survey period may have begun too early (and possibly violated assumptions of a closed population), and may not have been of sufficient duration to adequately sample marsh wren populations.

Seaside sparrow

Noise and wind both had negative effects on detection probability for seaside sparrows in 2015, but these effects were not always significant in every model. Seaside sparrows have a very faint call; it is logical that background noise and wind would impact an observer's ability to detect vocalizations, and other studies have found negative effects of both noise and wind on detection probability (Hunter et al., 2017; Leggett, 2014; Nuse et al., 2015). Julian date was negatively associated with detection probability in 2016, and this may be due to breeding or nesting activities.

The same model was ranked the highest for both the 2015 and 2016 seasons. Increasing Euclidean distance to urban features was positively associated with seaside abundance; although this effect was not significant in the 2015 analysis. Proportion of the landscape comprised of forested habitat and non-forested habitat within in 7,850 ha was negatively associated with seaside abundance in all models. These findings are supported by results found in other studies; Leggett, 2014 found that seaside sparrow occupancy decreased when the amount of unsuitable habitat (development or non-marsh) increased, as did another study in the Gulf of Mexico (Rush et al., 2009), and increasing distance to forested area was positively associated with seaside sparrow abundance (Nuse et al., 2015). Seaside sparrows are marsh-specialists, and as such, are sensitive to both anthropogenic disturbances and the presence on non-marsh habitat (Post, 2009). The context of the landscape surrounding wetlands can impact marsh birds (Crewe and Timmermans, 2005; DeLuca et al., 2004; Smith and Chow-Fraser, 2010); Quesnelle et al. 2013 found that marsh-obligate species were more sensitive and responded negatively to anthropogenic disturbances around wetlands than marsh-generalist species. Both urban and non-marsh areas may be a source of predators, which may be an explanation for this observed sensitivity. Competition from generalist species may also be a contributing factor. In the pooled analysis, the proportion of *Spartina alterniflora* within 3.14 ha had a positive effect on abundance; seaside sparrows are known to use this species for nesting habitat, and are likely to be found in these areas during the breeding season (Leggett, 2014; Post, 2009). Other variables considered in the seaside sparrow analyses were elevation, and mean salinity. Since seaside sparrows are saltmarsh obligates, they are associated with increasing salinity levels (Rush et al., 2009). In this study, mean salinity was positively associated with sparrow abundance. Elevation also tends to increase as distance from coastal areas increases, so this was also hypothesized to have a negative effect on seaside sparrow abundance, which was found in this study, but 95% confidence intervals did overlap zero. This is in contrast to Hunter et al. 2017, who found that elevation had a positive effect on seaside sparrow abundance. Model fit for the pooled data set was poor, and marginally acceptable for the other years. As mentioned previously, seaside sparrows were not initial target species, and the survey design may not be appropriate for this species.

Conclusion

Numerous studies show the importance of utilizing both local and landscape-scale variables in modeling avian distribution and abundance (Monfils et al., 2012; Spautz et al., 2006; Tozer et al., 2010), and the results from this study bolster this idea, as variables over a range of scales proved to be significantly associated with marsh bird abundance. Even though model selection results were variable across species, there were variables (e.g., Euclidean distance to forest, patch density of marsh) which routinely occurred in top models (e.g., clapper rail, seaside sparrow, marsh wren), suggesting that these variables may indeed be a good predictor of marsh bird abundance. However, there were several sources of potential error in this study which need to be addressed. First, lack of replicate visits to the same sample locations between years may have introduced spatial or temporal variability, which could lead to the discrepancy in results for several species in this analysis (clapper rail, KICL, and seaside sparrow to a lesser extent). Also, limited detections for many species may have further impeded model performance, particularly for KICL, marsh wrens, and seaside sparrows. As discussed previously, there was an issue of reliably identifying king and clapper rails in this study. This may explain why model performance varied between years and these species, and why pooling data for these species may not be appropriate. Pooling data sets across years was done to offset low detections for several species; however, approach is only appropriate if abundance remains constant across sample locations, which may or may not be true. Also, the appropriate scale is essential to clearly elucidating relationships; if an inappropriate scale is chosen, then this can either miss relationships when they are present, or falsely generate the appearance of relationships that do not exist. Other issues that are inherent to SMB surveys are the use of call-broadcast. It is well known that SMBs have low detection rates, and this will bias abundance estimates upwards. The use of call-broadcast increases detection probability, but it is not without its own set of caveats. My surveys were relatively long (11 minutes); this may have allowed birds to travel in and out of the survey area during counts, which could have led to the double-counting of individuals, and violated assumptions. Birds may also move towards the call-broadcast, which may contribute to unrealistically high estimates of abundance. Further exploration of the use of call-broadcast and effects on detection probability is warranted. Also, survey timing and duration may not be suitable for passerine species such as marsh wrens and seaside sparrows. Overall, the use of models which include both local and landscape scales does seem to be beneficial for modeling marsh bird abundance. Landscape variables may be of particular relevance to wetland birds, as these variables may be an indicator of habitat quality. Landscape-scale variables can be a tool that managers use to assess potential impacts of SMBs to human activities in and around the Preserve.

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Table 2.1. Choice of scales used in this analysis based on literature review and hypothesized biological relevance to SMBs.

Variable	**Biological Relevance**	**Reference**
0.79 ha (50-m radius)	Within range of local scale (home range) for SMBs (e.g., clapper rail)	Moffett et al., 2014; Rush et al., 2010a; Spautz et al., 2006; Stralberg et al., 2010
3.14 ha (100-m radius)	Within range of local scale (home range) for SMBs	Monfils et al., 2012; Rush et al., 2010
50.24 ha (400-m radius)	Within range of local scale (home range) for SMBs (e.g., least bittern)	Irvin, 2013, Poole et al., 2009
706.50 ha (1.5-km radius)	Within range of landscape scale (anthropogenic disturbance, predators, non-suitable habitat)	de la Casa-Resino et al., 2014; Lopez et al., 2006; Quesnelle et al., 2013, Rodewald, 2001
7,850 ha (5.0-km radius)	Within range of landscape scale (may be an indication of quality: anthropogenic disturbance, predators, non-suitable habitat)	Bolenbaugh et al., 2011; Crewe and Timmermans, 2005; de la Casa-Resino et al., 2014; Lopez et al., 2006; Rehm and Baldassarre, 2007
Euclidean distance	Distance to anthropogenic influence (contaminants, predators, non-suitable habitat)	Bolenbaugh et al., 2011; Crewe and Timmermans, 2005; de la Casa-Resino et al., 2014; Lopez et al., 2006; Rehm and Baldassarre, 2007

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Table 2.2. Covariates names and descriptions used in models for secretive marsh birds in this study. 'X' indicates the variable was included in models for that species. Specific models evaluated are listed in Appendix B.

Variable Name	**Variable Description**	**CLRA**	**KICL**	**MAWR**	**SESP**
area_mn_1_1500m	Mean patch area of marsh within 706.50 ha	X	X	X	
area_mn_1_400m	Mean patch area of marsh within 50.24 ha				X
area_mn_1_400m+(area_mn_1_400m)^2	Quadratic form of mean patch area of marsh within 50.24 ha		X		
ed_1_1500m	Edge density of marsh within 706.50 ha	X	X		
ed_1_400m	Edge density of marsh within 50.24 ha	X			
ed_1_5000m	Edge density of marsh within 7,850 ha	X			
ed_2_400m	Edge density of water within 50.24 ha	X			
ed_landcover_15k_fornat1nd	Euclidean distance to forest	X	X	X	
ed_landcover_15k_nonforn1nd	Euclidean distance to non-forested natural			X	
ed_landcover_15k_urban1nd	Euclidean distance to urban	X		X	X
ed_landcover_15k_water1nd	Euclidean distance to water			X	
iji_1_5000m	Interspersion juxtaposition index of marsh within 7,850 ha	X			
iji_1_5000m +(iji_1_5000m)^2	Quadratic form of interspersion juxtaposition index of marsh within 7,850 ha		X		
log(AREA_MARSH_M2)	Parameter to account for unequal area surveyed	X	X	X	X

Variable Name	Variable Description	CLRA	KICL	MAWR	SESP
lsi_1_400m	Landscape shape index of marsh within 50.24 ha	X			
MEAN_SAL_PPT	Mean salinity in (ppt)	X	X		X
para_mn_1_1500m	Mean perimeter to area ratio of marsh within 706.50 ha	X			
pd_1_1500m	Patch density of marsh within 706.50 ha	X	X		
pd_1_5000m	Patch density of marsh within 7,850 ha	X	X		
pd_1_5000m+(pd_1_5000m)^2	Quadratic form of patch density of marsh within 7,850 ha	X			
pd_4_5000m	Patch density of agriculture within 7,850 ha	X			
pland_1_1500m+(pland_1_1500m)^2	Quadratic form of proportion of marsh within 706.50 ha			X	
pland_1_5000m	Proportion of marsh within a 7,850 ha	X	X	X	X
pland_3_5000m	Proportion of urban within a 7,850 ha	X		X	X
pland_4_5000m	Proportion of agriculture within a 7,850 ha	X	X		
pland_5_5000m	Proportion of forest within a 7,850 ha				X
pland_6_5000m	Proportion of non- forested natural within a 7,850 ha				X
saltmarsh_junc10_mw100m	Proportion of *Juncus romerianus* within 3.14 ha	X	X		X
saltmarsh_junc10_mw50m	Proportion of *Juncus romerianus* within 0.785 ha	X	X	X	X
saltmarsh_spar10_mw100m	Proportion of *Spartina alterniflora* within 3.14 ha				X

Variable Name	Variable Description	CLRA	KICL	MAWR	SESP
saltmarsh_spar10_mw50m	Proportion of *Spartina alterniflora* within 0.785 ha	X		X	X
secn_dem_mtr	Elevation in meters		X		X
shape_mn_1_400m	Mean shape of marsh patches within 50.24 ha	X			X

Table 2.3. Covariate estimates for top clapper rail models for each year. Models were ranked by AICc. ΔAICc is the difference in AICc units from the highest- ranking model. Model AICc weights and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. See Table 2.2 for description of covariate names.

Year	K	AICc	Δ AICc	AICcWt	Cum. Wt	$\hat{\beta}_i$	Estimate	LCL	UCL	SE
2015	7	392.81	0.00	0.98	0.98	lam(Int)	0.54	-1.66	2.73	1.12
						lam(log(AREA_MARSH_M2))	0.15	-0.05	0.35	0.10
						lam(pd_1_5000m)	1.11	0.87	1.35	0.12
						lam(I(pd_1_5000m^2))	-0.53	-0.76	-0.30	0.12
						p(Int)	-1.41	-2.62	-0.20	0.62
						p(julian_date)	0.01	0.00	0.02	0.01
						p(min_af_sunrise)	0.00	-0.01	0.00	0.00
2016	7	482.20	0.00	1.00	1.00	lam(Int)	2.13	0.46	3.79	0.85
						lam(log(AREA_MARSH_M2))	0.03	-0.11	0.17	0.07
						lam(ed_1_1500m)	-0.01	-0.13	0.12	0.06
						lam(pland_4_5000m)	-1.01	-1.24	-0.78	0.12
						p(Int)	-2.06	-3.35	-0.77	0.66
						p(air_temp)	0.02	0.00	0.03	0.01
						p(noise)	-0.04	-0.21	0.12	0.09
Pooled	8	1002.38	0.00	1.00	1.00	lam(Int)	0.78	-0.74	2.29	0.77
						lam(log(AREA_MARSH_M2))	0.10	-0.04	0.24	0.07
						lam(pd_1_5000m)	0.52	0.42	0.62	0.05
						lam(saltmarsh_spar10_mw50m)	0.29	0.20	0.38	0.05
						p(Int)	-1.14	-2.09	-0.18	0.49
						p(julian_date)	0.01	0.00	0.02	0.00
						p(min_af_sunrise)	0.00	-0.01	0.00	0.00
						p(YEARyr2)	-0.21	-0.58	0.16	0.19

Table 2.4. Covariate estimates for top KICL models for each year. Models were ranked by AICc. ΔAICc is the difference in AICc units from the highest- ranking model. Model AICc weights and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. See Table 2.2 for description of covariate names.

Year	K	AICc	Δ AICc	AICcWt	Cum. Wt	$\hat{\beta}_i$	Estimate	LCL	UCL	SE
2015	6	123.53	0.00	0.34	0.34	lam(Int)	-11.97	-25.38	1.43	6.84
						lam(log(AREA_MARSH_M2))	0.99	-0.24	2.21	0.62
						lam(MEAN_SAL_PPT)	-1.39	-1.95	-0.83	0.29
						lam(secn_dem_mtr)	0.22	-0.27	0.70	0.25
						p(Int)	0.48	-0.98	1.94	0.75
						p(wind)	-0.27	-0.55	0.01	0.15
2015	5	124.45	0.92	0.21	0.55	lam(Int)	-29.68	-42.76	-16.59	6.68
						lam(log(AREA_MARSH_M2))	2.51	1.32	3.69	0.60
						lam(pd_1_5000m)	-2.59	-4.14	-1.04	0.79
						p(Int)	0.64	-0.64	1.92	0.65
						p(wind)	-0.32	-0.60	-0.04	0.14
2016	10	149.18	0.00	0.68	0.68	lam(Int)	-14.41	-29.33	0.51	7.61
						lam(log(AREA_MARSH_M2))	1.00	-0.04	2.03	0.53
						lam(pland_4_5000m)	5.11	0.34	9.89	2.44
						lam(pland_1_5000m)	2.61	0.09	5.14	1.29
						p(Int)	0.50	-2.33	3.33	1.44
						p(julian_date)	-0.03	-0.05	-0.01	0.01
						p(tidal_stageHIGH_TIDE)	-6.69	-24.50	11.11	9.08
						p(tidal_stageLOW_RISING)	-0.35	-0.98	0.27	0.32
						p(tidal_stageLOW_TIDE)	-0.21	-1.00	0.59	0.41
						p(noise)	-0.33	-0.84	0.18	0.26
Pooled	10	348.50	0.00	0.38	0.38	lam(Int)	-3.58	-8.51	1.34	2.51
						lam(log(AREA_MARSH_M2))	0.61	0.20	1.02	0.21
						lam(pd_1_1500m)	0.40	0.14	0.66	0.13
						p(Int)	0.04	-3.03	3.11	1.57
						p(julian_date)	-0.02	-0.03	0.00	0.01

Year	K	AICc	Δ AICc	AICcWt	Cum. Wt	$\hat{\beta}_i$	Estimate	LCL	UCL	SE
						p(tidal_stageHIGH_TIDE)	0.19	-0.48	0.86	0.34
						p(tidal_stageLOW_RISING)	0.18	-0.26	0.61	0.22
						p(tidal_stageLOW_TIDE)	0.10	-0.51	0.71	0.31
						p(YEARyr2)	-0.23	-0.70	0.24	0.24
						Zero-inflation	1.10	---	---	0.25
Pooled	10	348.88	0.38	0.31	0.69	lam(Int)	-2.54	-7.32	2.25	2.44
						lam(log(AREA_MARSH_M2))	0.53	0.13	0.93	0.20
						lam(ed_1_1500m)	0.66	0.21	1.10	0.23
						p(Int)	0.04	-3.05	3.14	1.58
						p(julian_date)	-0.01	-0.03	0.00	0.01
						p(tidal_stageHIGH_TIDE)	0.21	-0.46	0.88	0.34
						p(tidal_stageLOW_RISING)	0.15	-0.29	0.58	0.22
						p(tidal_stageLOW_TIDE)	0.02	-0.59	0.63	0.31
						p(YEARyr2)	-0.24	-0.73	0.25	0.25
						Zero-inflation	1.10	---	---	0.25

Table 2.5. Covariate estimates for top marsh wren models for each year. Models were ranked by AICc. ΔAICc is the difference in AICc units from the highest- ranking model. Model AICc weights and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. See Table 2.2 for description of covariate names.

Year	K	AICc	Δ AICc	AICcWt	Cum. Wt	$\hat{\beta}_i$	Estimate	LCL	UCL	SE
2015	8	342.34	0	0.47	0.47	lam(Int)	-5.60	-11.18	-0.01	2.85
						lam(log(AREA_MARSH_M2))	0.81	0.38	1.24	0.22
						lam(ed_landcover_15k_fornat1nd)	0.33	0.16	0.51	0.09
						lam(area_mn_1_400m)	-0.13	-0.32	0.06	0.10
						p(Int)	-2.19	-6.08	1.70	1.98
						p(noise)	-0.57	-0.84	-0.30	0.14
						p(wind)	-0.08	-0.18	0.02	0.05
						p(min_af_sunrise)	0.00	-0.01	0.00	0.00
2015	8	343.35	1.01	0.29	0.76	lam(Int)	-4.62	-9.43	0.19	2.46
						lam(log(AREA_MARSH_M2))	0.70	0.31	1.09	0.20
						lam(ed_landcover_15k_fornat1nd)	0.30	0.13	0.47	0.09
						lam(saltmarsh_spar10_mw50m)	0.08	-0.10	0.25	0.09
						p(Int)	-1.91	-4.81	0.99	1.48
						p(noise)	-0.56	-0.84	-0.28	0.14
						p(wind)	-0.07	-0.18	0.03	0.05
						p(min_af_sunrise)	0.00	-0.01	0.00	0.00
2015	8	344.05	1.72	0.20	0.96	lam(Int)	-4.79	-9.66	0.08	2.48
						lam(log(AREA_MARSH_M2))	0.69	0.27	1.11	0.21
						lam(ed_landcover_15k_fornat1nd)	0.30	0.12	0.48	0.09
						lam(saltmarsh_junc10_mw50m)	-0.01	-0.20	0.18	0.10
						p(Int)	-1.66	-3.97	0.65	1.18
						p(noise)	-0.55	-0.83	-0.27	0.14
						p(wind)	-0.08	-0.18	0.03	0.05
						p(min_af_sunrise)	0.00	-0.01	0.00	0.00
2016	7	283.53	0	0.68	0.68	lam(Int)	-9.10	-16.00	-2.21	3.52
						lam(log(AREA_MARSH_M2))	1.03	0.47	1.58	0.28

Year	K	AICc	Δ AICc	AICcWt	Cum. Wt	$\hat{\beta}_i$	Estimate	LCL	UCL	SE
						lam(ed_landcover_15k_fornat1nd)	0.20	0.02	0.38	0.09
						lam(saltmarsh_spar10_mw50m)	-0.33	-0.60	-0.06	0.14
						p(Int)	2.60	-2.04	7.23	2.36
						p(julian_date)	-0.04	-0.06	-0.02	0.01
						p(air_temp)	-0.01	-0.05	0.04	0.02
Pooled	8	700.18	0	0.37	0.37	lam(Int)	0.85	-1.63	3.33	1.27
						lam(log(AREA_MARSH_M2))	0.06	-0.16	0.29	0.11
						lam(ed_landcover_15k_fornat1nd)	0.21	0.09	0.34	0.06
						lam(saltmarsh_junc10_mw50m)	0.09	-0.07	0.24	0.08
						p(Int)	1.00	-0.50	2.51	0.77
						p(julian_date)	-0.01	-0.02	0.00	0.01
						p(air_temp)	-0.04	-0.08	0.00	0.02
						p(YEARyr2)	1.51	-0.25	3.28	0.90
Pooled	8	701.17	0.99	0.22	0.59	lam(Int)	0.58	-1.98	3.14	1.30
						lam(log(AREA_MARSH_M2))	0.09	-0.15	0.32	0.12
						lam(ed_landcover_15k_fornat1nd)	0.21	0.09	0.34	0.06
						lam(area_mn_1_400m)	0.03	-0.11	0.18	0.08
						p(Int)	1.02	-0.50	2.53	0.77
						p(julian_date)	-0.01	-0.02	0.00	0.01
						p(air_temp)	-0.04	-0.08	-0.01	0.02
						p(YEARyr2)	1.66	-0.11	3.44	0.90
Pooled	8	701.31	1.14	0.21	0.8	lam(Int)	0.40	-2.04	2.83	1.24
						lam(log(AREA_MARSH_M2))	0.10	-0.12	0.32	0.11
						lam(ed_landcover_15k_fornat1nd)	0.22	0.09	0.34	0.06
						lam(saltmarsh_spar10_mw50m)	0.02	-0.13	0.16	0.07
						p(Int)	1.03	-0.48	2.54	0.77
						p(julian_date)	-0.01	-0.02	0.00	0.01
						p(air_temp)	-0.04	-0.08	-0.01	0.02
						p(YEARyr2)	1.64	-0.12	3.40	0.90

Table 2.6. Covariate estimates for top seaside sparrow models for each year. Models were ranked by AICc. ΔAICc is the difference in AICc units from the highest- ranking model. Model AICc weights and number of parameters (K), and standard errors (SE) and 95% confidence intervals of covariate estimates, are also shown. See Table 2.2 for description of covariate names.

Year	K	AICc	Δ AICc	AICcWt	Cum. Wt	$\hat{\beta}_i$	Estimate	LCL	UCL	SE
2015	7	229.97	0.00	0.35	0.35	lam(Int)	-6.63	-14.50	1.24	4.01
						lam(log(AREA_MARSH_M2))	0.65	-0.07	1.36	0.37
						lam(pland_5_5000m)	-0.74	-1.08	-0.40	0.17
						lam(ed_landcover_15k_urban1nd)	0.24	-0.02	0.50	0.13
						p(Int)	0.56	-0.74	1.86	0.66
						p(wind)	-0.20	-0.38	-0.01	0.09
						p(noise)	-0.60	-1.20	0.01	0.31
2015	7	230.81	0.84	0.23	0.58	lam(Int)	-10.54	-19.39	-1.69	4.52
						lam(log(AREA_MARSH_M2))	1.00	0.20	1.80	0.41
						lam(MEAN_SAL_PPT)	0.98	0.46	1.50	0.27
						lam(secn_dem_mtr)	-0.18	-0.54	0.18	0.18
						p(Int)	0.89	-0.18	1.97	0.55
						p(wind)	-0.24	-0.43	-0.05	0.10
						p(noise)	-0.65	-1.23	-0.06	0.30
2015	7	231.15	1.18	0.19	0.77	lam(Int)	-7.00	-14.73	0.74	3.95
						lam(log(AREA_MARSH_M2))	0.68	-0.02	1.39	0.36
						lam(saltmarsh_junc10_mw50m)	-0.28	-0.71	0.15	0.22
						lam(pland_5_5000m)	-0.61	-0.94	-0.27	0.17
						p(Int)	0.70	-0.48	1.88	0.60
						p(wind)	-0.20	-0.38	-0.01	0.09
						p(noise)	-0.72	-1.29	-0.15	0.29
2016	7	95.12	0.00	0.87	0.87	lam(Int)	-9.36	-23.04	4.31	6.98
						lam(log(AREA_MARSH_M2))	0.68	-0.51	1.87	0.61
						lam(pland_5_5000m)	-2.22	-3.55	-0.90	0.68
						lam(ed_landcover_15k_urban1nd)	0.86	0.26	1.46	0.31

Year	K	AICc	Δ AICc	AICcWt	Cum. Wt	$\hat{\beta}_i$	Estimate	LCL	UCL	SE
						p(Int)	7.32	-1.31	15.95	4.40
						p(air_temp)	0.04	-0.10	0.18	0.07
						p(julian_date)	-0.10	-0.17	-0.02	0.04
Pooled	7	385.81	0.00	0.74	0.74	lam(Int)	2.80	-0.30	5.90	1.58
						lam(log(AREA_MARSH_M2))	-0.28	-0.57	0.01	0.15
						lam(saltmarsh_spar10_mw100m)	0.36	0.14	0.58	0.11
						lam(pland_6_5000m)	-0.55	-0.86	-0.24	0.16
						p(Int)	1.06	-0.57	2.70	0.84
						p(air_temp)	-0.05	-0.12	0.02	0.04
						p(YEARyr2)	1.55	-1.86	4.95	1.74

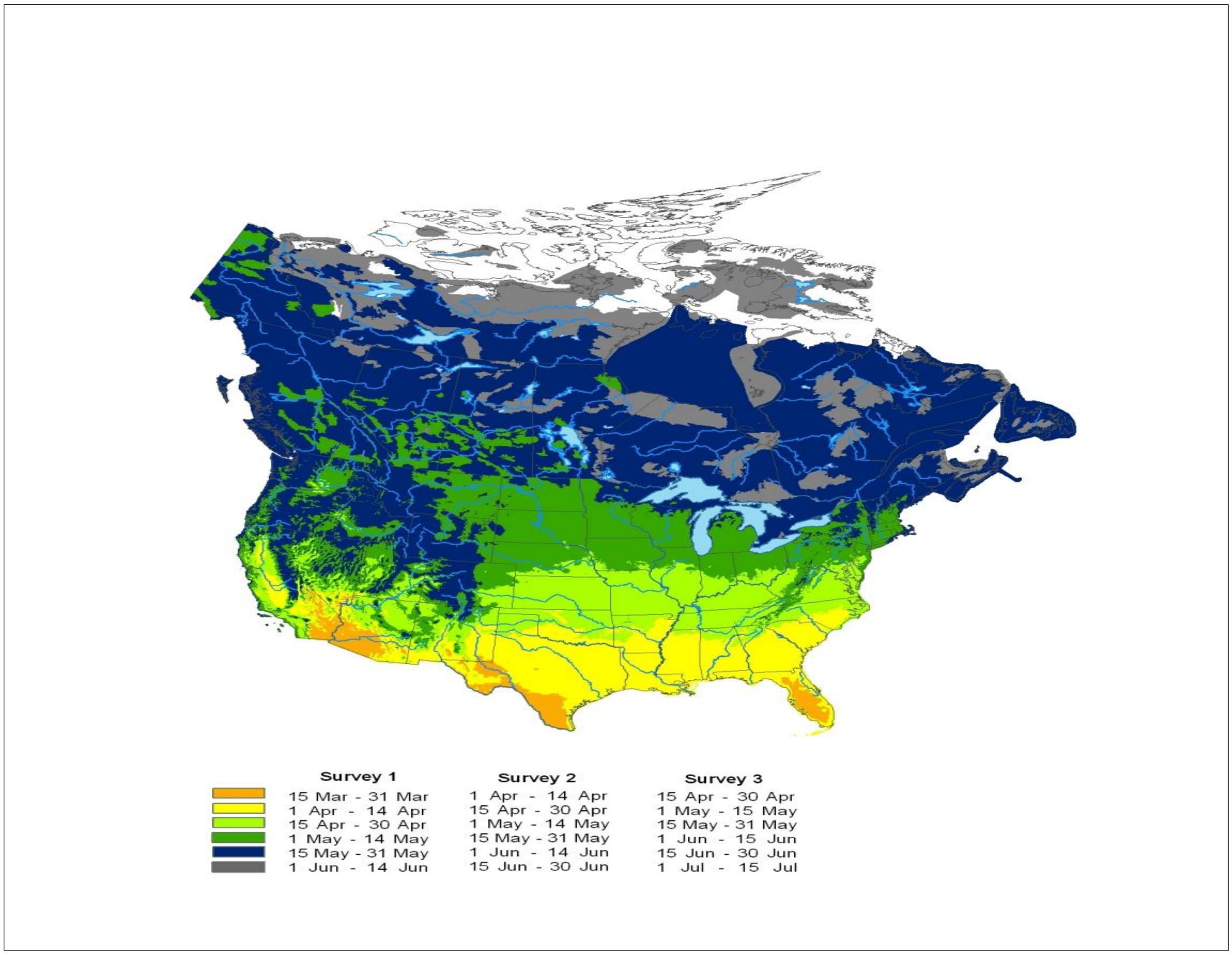

Figure 2.1. Recommended survey intervals for secretive marsh birds within North America according to The Standardized North American Marsh Bird Monitoring Protocol (Conway, 2011).

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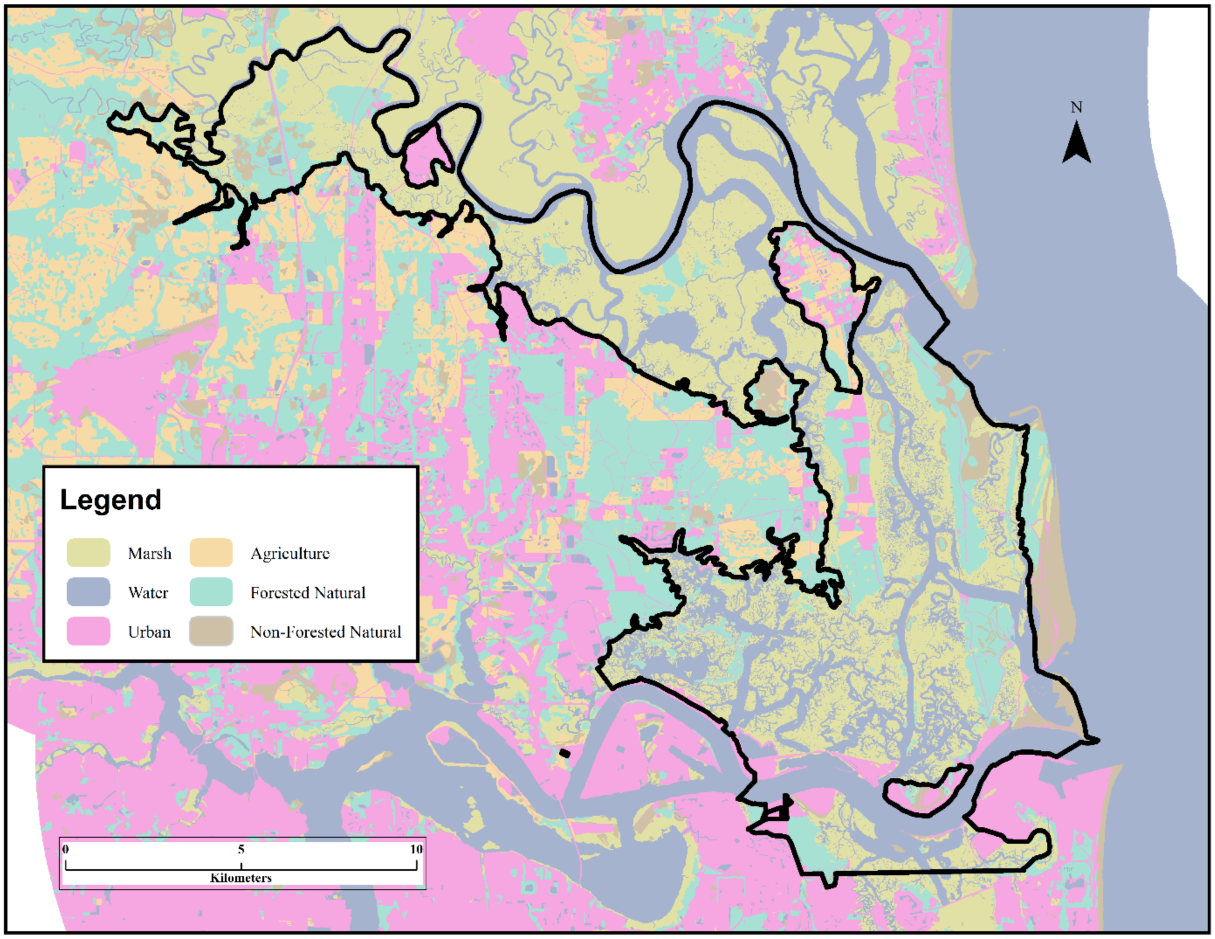

Figure 2.2. Reclassified land cover map used in the 2015-2016 species abundance analysis.

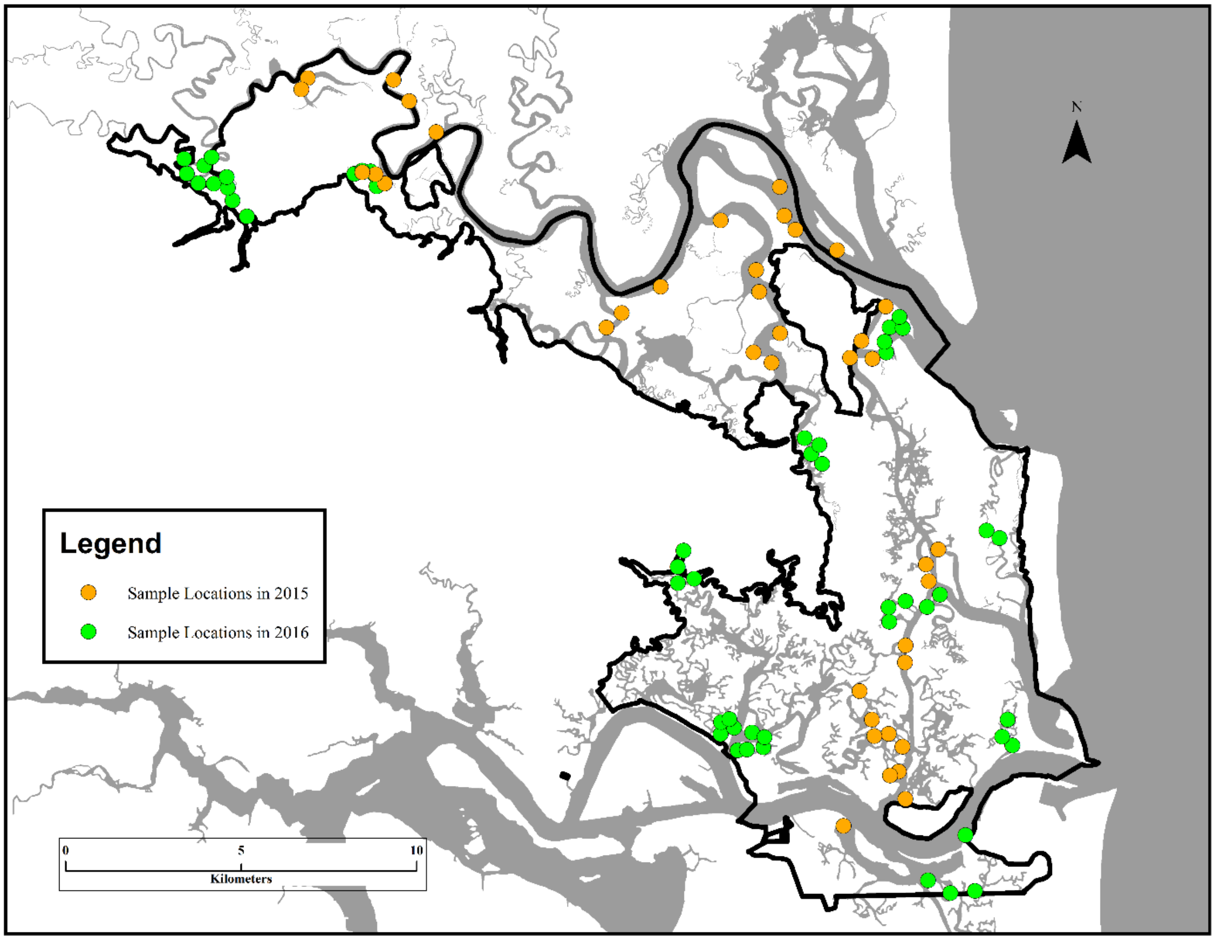

Figure 2.3. Sample locations surveyed for the 2015-2016 breeding seasons within the Timucuan Ecological & Historic Preserve, Jacksonville, Florida.

CHAPTER 3

METAL CONTAMINANT, BIOCHEMICAL, AND CELLULAR BLOOD LEVELS IN WILD-CAUGHT CLAPPER RAIL (*RALLUS CREPITANS*) IN THE TIMUCUAN ECOLOGICAL & HISTORIC PRESERVE, JACKSONVILLE, FLORIDA[1]

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Abstract

The clapper rail (*Rallus crepitans*) is a marsh bird native to coastal saltmarshes in northern Florida. Populations are currently stable, but appear to be declining. Possible reasons for negative population trends include the reduction and degradation of coastal marshes due to contaminants. Contaminants are associated with adverse effects in birds such as alteration of immune function and reproductive abnormalities, both of which have implications for the persistence of avian populations. All sampling activities occurred within the administrative boundary of the Timucuan Ecological & Historic Preserve. Clapper rails (N=15) and composite invertebrate samples (N=28) were captured and sampled for heavy metals using Inductively Coupled Plasma Mass Spectrometry. Complete blood counts and biochemistry panels were performed as a health assessment for clapper rails. Some metals and health parameters were elevated in both clapper rail and invertebrate samples, but there is a lack of data available for comparison and future studies are recommended.

INDEX WORDS: Clapper rail, heavy and trace metals, biochemistry, complete blood count, blood metal levels, avian blood parameters

Introduction

The clapper rail (*Rallus crepitans*) is a member of the family Rallidae, which includes rails, gallinules, and coots. The clapper rail is a denizen of coastal saltmarshes, and occurs south from the northeastern Atlantic coast through the southeastern coast of Texas, islands in the Caribbean sea, and the southern Californian coast (Eddelman and Conway, 1994). Clapper rails are a migratory species, but occur year-round in the southeastern portion of their range. Clapper rails are the second largest rail species in North America, and range from 160-400 grams in body weight and have an adult body length ranging from 32-41 cm (Rush et al., 2012). The clapper rail phenotype varies by geographic location, but is generally gray to brownish in overall body plumage coloration, with white and brown barring on the flanks, and a long, dull orange, slightly decurved bill (Eddelman and Conway, 1994). The clapper rail is a game species, but hunting pressure is thought to have a negligible effect on populations in the eastern United States (Eddelman and Conway, 1994; Raftovich et al., 2014; Rush et al., 2012). According to the International Union for Conservation of Nature's (IUCN) Red List, clapper rails are listed as a species of "least concern", but populations appear to be declining. Possible reasons for negative population trends include the alteration, reduction, and degradation of coastal marshes due to heavy and trace metal contaminants (hereafter HATMC) (Eddelman and Conway, 1994; Rush et al., 2012).

There is some debate as to how the term "heavy metal" is defined (Duffus, 2002). For the purposes of this research project, heavy metals are defined as metallic elements that exhibit high densities relative to other elements and include: arsenic, cadmium, chromium, mercury, and lead. These metals pose a threat to both human and environmental health (Jula, 1971; Lawrence and McCabe, 1995; Yu, 2001). Trace metals are those that occur naturally in the environment in limited quantities. Trace metals include: chromium, copper, cobalt, iron, magnesium, selenium, and zinc. Many trace metals are essential elements, or those that are required to maintain homeostatic functions. Of the previous list, copper, iron, magnesium, selenium, and zinc are essential elements (Goyer, 1995; Goyer and Clarkson, 2001; Lawrence and McCabe, 1995).

Degradation of coastal marshes is an ongoing problem, particularly in Jacksonville, Florida. In the past, point-source pollution from superfund sites, national pollutant discharge elimination systems, solid waste plants, and automobiles were the predominant sources of contaminants such as HATMC in surface waters; but currently, non-point source pollution from urban storm water runoff, septic systems, agricultural and industrial runoff, atmospheric deposition (e.g. mercury and lead), and marinas and boatyards is the primary source of those contaminants in north Florida waters (Anderson et al., 2005; DeBusk, 2000; Maher, 1997). There are several areas within Jacksonville that reflect the legacy and current effects of human practices. Industrial operations are the major source of contaminants in this region; in 2013, 4.8 million pounds of chemicals were released into the atmosphere and surface waters of the Lower St. Johns watershed (LSJW hereafter), with the majority of releases (91%) as atmospheric emissions (University of North Florida, 2016). Sediment samples collected from Chicopit Bay near the Preserve contained concentrations of arsenic, chromium, lead, and zinc above the NOEL (no observed effect level) (Anderson et al., 2005). Water quality stations in close proximity to the Preserve have also detected cadmium, copper, lead, mercury, and nickel levels in exceedance of water quality standards (Anderson et al., 2005). The status of metals in the main stem waters of the LSJW is satisfactory except for copper and silver; in the tributaries, levels are deemed satisfactory for arsenic, nickel, and zinc, but unsatisfactory for cadmium, copper, lead, and silver (University of North Florida, 2016). For sediments, the general trend over the last two decades is that metals are elevated over the natural background levels throughout the LSJW (University of North Florida, 2016).

The issues mentioned above are relevant for sites located within the Preserve as well. The Preserve is adjacent to the Jacksonville Harbor Navigation Project which spans the St. Johns river from its mouth at the Atlantic Ocean near Mayport, to river mile 20 in Jacksonville, Florida (U.S. Army Corps of Engineers, 2014). The purpose of the project is to deepen and maintain channel width via dredging for larger cargo ship access. Environmental concerns related to dredging activities include: increased salinity levels, disturbance to submerged aquatic vegetation, disruption of sediments, increased bank erosion from increased wave action, and increased water turbidity due to rock blasting; mitigation efforts therefore focus on addressing these concerns (U.S. Army Corps of Engineers, 2014). In addition, a water quality assessment in 2008 rated nitrogen and phosphorus levels as “fair” or “poor” for several stations; arsenic, cadmium and silver sediment concentrations were also rated as either “fair’ or “poor” for several locations (Gregory et al., 2011). Certain HATMC can either biomagnify or bioaccumulate and affect species which forage within marshes such as clapper rails; however, the effects of these metals on avian communities in this region are not known (DeVivo et al., 2008; United States Geological Survey Patuxent Wildlife Research Center; University of North Florida, 2016).

HATMC are problematic for three main reasons: they persist for extremely long periods in the environment, can bioaccumulate and/or biomagnify, and be converted into more toxic forms (Waalkes, 1995). Additionally, it can be years before clinical signs of chronic heavy-metal poisoning develop (Goyer and Clarkson, 2001; Jula, 1971). HATMC can negatively impact immunologic, reproductive, endocrine, and early-developing systems within an organism (Lawrence and McCabe, 1995; Thomas, 1995; Waalkes, 1995; Yu, 2001). Metals produce toxic effects by the following general mechanisms: enzyme alteration (i.e. inhibition or activation), disruption of cellular structure (i.e. organelles and sub-cellular organelles), disruption of organ function (i.e. kidneys, lung, brain, ovaries, and testicles), and many are carcinogenic (Leblanc, 2004). HATMC in general are known to cause detrimental effects in several taxa, including birds (Yu, 2001).

The effects mentioned above have also been documented in clapper rails. For example, contamination is associated with various egg abnormalities; clapper rail eggs in contaminated marshes in Brunswick, Georgia exhibited thinner shells (Novak et al., 2006; Rodriguez-Navarro et al., 2002), while California clapper rail (*Rallus longirostrus obsoletus*) eggs collected in contaminated portions of the San Francisco Bay had higher incidences of embryo malpositions, decreased hatchability, presence of deformities, and embryonic hemorrhaging (Schwarzbach et al., 2006). Body condition is often affected by the presence of HATMC; decreases in body mass of endangered California clapper rails were associated with higher concentrations of mercury in blood and feathers, which were attributable to the capture site (Ackerman et al., 2012). Damage to DNA has also been found, and DNA strand breakage was documented in adult rails collected in Brusnwick, Georgia from contaminated sites, while rails from reference sites did not exhibit this finding (Novak et al., 2006). Additionally, higher mercury levels were associated with increased calcium: phosphorus ratios in clapper rail chicks which may alter bone maturation (Rodriguez-Navarro et al., 2006). In this same area of Brunswick, Georgia, it appears the population age-structure (i.e. the ratio of HY (hatch-year) to adult birds) may be altered by contaminants (Gaines et al., 2011). The continued use and exploration of various biomarkers will better elucidate the effects of HATMC on health and long-term persistence of clapper rail populations.

Biomarkers are used to assess health in response to metal exposure. Commonly used biomarkers include measuring metal concentrations in blood, urine, and organ tissues (Goyer and Clarkson, 2001; Kakkar and Jaffery, 2005). Additionally, levels of ALAD (delta-aminolevulinate dehydratase for lead), cholinesterase, DNA adduct concentration, cytochrome P450, oxidative stress, plasma enzymes, eggshell thickness, and hematological parameters are often evaluated (Kakkar and Jaffery, 2005; Yu, 2001). Complete blood counts (CBC hereafter) and biochemistry panels are two tests which measure various hematological parameters. A CBC generally consists of the following components: a leukocyte (white blood cell) count, a leukocyte differential count, an erythrocyte (red blood cell) count, hematocrit (Hct), hemoglobin (Hbg), total protein, and a platelet count (Knoll and Rowell, 1996). A biochemistry panel typically includes measures of electrolytes, liver and kidney enzymes, total protein, glucose, anion gap, total carbon dioxide, cholesterol, and triglycerides (Harr, 2006). Both of these panels in conjunction can assess health and organ function, and also act as a health screening tool (Harr, 2006; Knoll and Rowell, 1996).

Study Objectives

My objectives were 1) to determine if metal contaminants were present in clapper rail blood samples, and 2) determine if the presence of metal contaminants were associated with clapper rail health by examining biological samples collected from clapper rail blood and invertebrates (which represent a prey base and source of exposure to contaminants) within the Preserve.

Study Area

All sampling activities occurred within the administrative boundary of the Timucuan Ecological & Historic Preserve, located in Jacksonville, Florida (Figure 1.1). The total areal extent of the park is approximately 46,000 acres which is jointly managed by the National Park Service, the state of Florida, and the city of Jacksonville (National Park Service, 2006). Coastal wetlands and waterways constitute approximately 75% of this acreage. Estuarine wetlands within the Preserve are dominated by smooth cordgrass (*Spartina alterniflora*) and black needlerush (*Juncus roemerianus*) communities (Brody, 1994; Carlton, 1977). The surrounding uplands of the Preserve are diverse and include habitats such as: coastal strand, shell middens, maritime hammock, pine flatwoods, freshwater wetlands, and pine plantations (Anderson et al., 2005; Elston et al., 2008; Tardona, 1997). The Preserve encompasses portions of both the Nassau river watershed (NRW hereafter) to the north, and the LSJW to the south. Both watersheds face anthropogenic stressors from the surrounding landscape. The NRW is much less urbanized than the LSJW, but it is affected by the presence of silvicultural and agricultural operations, increased residential development, and periodic mercury advisories for fish consumption (Anderson et al., 2005; DeVivo et al., 2008; Florida Department of Environmental Protection, 2007; Gregory et al., 2011). The LSJW, however, is plagued by numerous issues related to high-density development and urbanization: eutrophication (i.e. increased nitrogen and phosphorus), fecal coliform bacteria, increased sedimentation due to surface water runoff, loss of riparian corridors and aquatic habitat due to urban development and dredging, and introduction of contaminants, such as pesticides, herbicides, and heavy metals such as arsenic, lead, mercury and silver (Anderson et al., 2005; Maher, 1997; St. Johns River Keeper, 2011; University of North Florida, 2016). Water quality is likely to remain an important issue in this region, as Jacksonville is ranked as the 12th most populous city in the United States, and population trends are only increasing (U.S. Census Bureau, 2010).

Methods

Clapper rail capture techniques

Capture activities were conducted from 16 May-16 June for both the 2015 and 2016 seasons. Capture efforts were restricted to daylight hours for feasibility and safety reasons. Areas that were noted to have high clapper rail activity and good accessibility were targeted for capture efforts. Several methods were attempted to capture clapper rails, but were not successful. These included locating individuals using thermal camera imagery and dip nets, and also using drag-lines to flush clapper rails into nets. Ultimately, clapper rails were captured using two different methods; both juvenile and adult clapper rails were targeted. Juveniles were caught by searching the marsh during high tide. Juveniles were first located by identifying calling pairs of adults, and then searching small *Spartina alterniflora* islands around these individuals. All juveniles were hand caught using this method. Adults were captured using a method adapted by Jared Feura et al. (pers. comm.) which consists of a handmade net setup with playback of conspecific calls. A narrow net lane was constructed by using a two-by-four board with a rope attached to tramp down the vegetation. Net lanes were kept narrow (~1.5 feet wide) so the net was less conspicuous to clapper rails. Mist nets (30-mm mesh) were cut to the height of the vegetation in the capture areas (~3-3.5 ft), and were approximately 12-15 feet in length. The bottom trammel of the net was lightly staked down using tent stakes. Originally, speakers connected remotely with Bluetooth-enabled devices were used to broadcast calls. Due to the density of the marsh vegetation, Bluetooth connections were not reliable, and 12-foot speaker cables were used in place of this. One person sat on each side of the net. Two speakers were placed in the center on the net setup, on both sides. Depending on which side a clapper rail approached the net, conspecific calls from the opposite speaker were used, to lure the bird into the center of the net. Clapper rail capture locations are depicted in Figure 3.1. All banding and sampling activities were conducted under the appropriate university, state, federal, and park permits (the University of Georgia animal use protocol A2015 02-002-Y1-A0, Florida Fish and Wildlife Conservation Commission scientific collecting permit LSSC-15-00039, Federal Bird Banding Permit 22587, and the National Park Service scientific research and collecting permit TIMU-2015-SCI-003).

Biological sample collection

Once a bird was captured, it was weighed and a blood sample in milliliters not exceeding 1% of the bird's body weight in grams was collected using a 25-gauge needle from the right jugular vein. To minimize handling stress, and due to the fact the health status was unknown, the minimum blood volume required for analysis (0.6 milliliters) was collected unless it was a very large individual. Metal panels were prioritized when a full sample was not obtained. Whole blood samples were collected into BD Microtainer® lithium heparin tubes for CBC, biochemistry panels, and metals analyses. Blood smears for leukocyte differentials were made at the time of blood collection. Blood samples were immediately stored in a cooler and transported directly to the University of Florida's Veterinary Teaching Hospital Clinical Pathology Laboratory for same-day analysis. Blood samples for metal analyses were frozen and sent to the University of Georgia Environmental Analysis Laboratory. Morphometric measurements such as right metatarsal length, right wing chord, culmen length, and body condition index using a keel palpation were collected. The presence of any abnormalities or external parasites was also noted. Photographs of the head, retrices, ventrum, and dorsum of each bird were also taken. Birds were aged as HY or ADULT using plumage characteristics, and a USGS aluminum band size 5 was placed on the right metatarsal.

Prey-base invertebrate collection

Composite invertebrate samples (~15 grams/sample) were collected from capture sites when possible, foraging areas, and areas where high clapper rail activity (i.e. likely foraging areas) was documented. Composite samples were collected to characterize the local diet of clapper rails at a given location. Composite samples included fiddler crabs (Uca spp.), marsh crabs (Sesarma spp.), Eastern mud snails (Ilyanassa spp.), and periwinkle snails (Littorina spp.). Three types of composite samples were collected: Crustaceans (Uca spp. and Sesarma spp.), Mollusks (Ilyanassa spp. and Littorina spp.), and Crustacean/Mollusks combination, comprised of a mixture of the previously mentioned genera. Invertebrates were bagged, rinsed with water, and frozen until analysis. Samples were sent to University of Georgia Environmental Analysis Laboratory for the same suite of metals as the clapper rail blood samples (see next section). Invertebrate sample locations are depicted in Figure 3.2. Refer to Appendix F, Figures F.1-F.6 for depictions of the clapper rail and invertebrate sample collection process.

Analysis of clapper rail blood and composite invertebrate samples

Clapper rail blood samples and composite invertebrate samples were analyzed for the following metals: arsenic, cadmium, chromium, copper, lead, nickel, mercury, silver, and zinc. Samples were analyzed at the University of Georgia Environmental Analysis Laboratory using inductively-coupled mass spectrometry. Prior to analysis, composite invertebrate samples were dried under a vacuum. Blood and dried invertebrate samples were microwave digested following EPA Method 3052 'Microwave Assisted Acid Digestion Of Siliceous And Organically Based Matrices'. Samples were analyzed according to EPA Method 200.8, Revision 5.4 'Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma-Mass Spectrometry'. Quality control and assurance control methods followed those outlined in EPA Method 200.8, Revision 5.4 'Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma-Mass Spectrometry', and include re-calibration, re-zeroing, replication, individual calibration of all elements in a sample run over the concentration range of interest, and use of check standards to ensure proper calibration (Appendix G, Figures G.1-G.3). Complete blood counts and biochemistry panels were performed at the University of Florida Veterinary Teaching Hospital Clinical Pathology Laboratory. Complete blood counts are performed manually by a clinical pathologist, and biochemistry panels were analyzed using a Siemens Dimension ® Xpand Plus Integrated Chemistry System.

Results

Clapper blood metal levels

A total of 15 individual clapper rails were captured across both seasons (6 adults, 9 HY). For the 2015 season, 6 HY birds were captured. It was assumed that the 2015 HY birds came from two different broods (each brood with 3 HY birds), since all individuals were captured together at two separate locations and were at differing stages of development. For the 2016 season, 3 HY birds and 6 adults were captured. The 3 HY birds were assumed to be a part of the same brood, since they were approximately the same age and found in the same location, on the same date. Metal panels were collected and are summarized for all captured individuals (Table 3.1). Due to the lack of data regarding whole blood metal concentrations for clapper rails, results from this study are compared to other avian values when available; refer to Appendix H for references of avian metal levels cited in this study. When applicable, site status (e.g. contaminated areas, reference areas, known toxic thresholds, and observed biological effects), diet type, and age categories of select avian species are also specified (Appendix H, Tables H.1-H. 8). AOU codes are used where applicable for species' descriptions in metal tables.

Avian arsenic levels

In general, arsenic levels for wild birds ranged from below detection limits to 1.6 ppm. Captive psittacine species' plasma arsenic levels ranged from 0.078-0.093 ppm, while adult pied flycatchers (*Ficedula hypoleuca*) and nestling black-crowned night herons (*Nycticorax nycticorax*) from reference areas were on average 0.11 and 0.128 ppm, respectively. Pied flycatchers collected from contaminated areas had blood arsenic levels ranging from 0.12 ppm-0.33 ppm. The range for arsenic values for clapper rails within this study were substantially higher than other published literature values (0.05-15.51 ppm, this study). Adult clapper rails on average had higher levels of arsenic, but there were several HY birds with much higher levels than the average adult levels. The LSJW had higher average levels than the NRW.

Avian cadmium levels

Cadmium levels for wild bird ranged from not detected to 7.25 in plasma levels of black vultures (*Coragyps atratus*). Birds collected from reference sites typically had levels that were not detectable up to 1.1 ppm. Adult wood storks (*Mycteria americana*) collected from contaminated sites were higher, and ranged from 4.3-5.3 ppm, while mallards (*Anas platyrhynchos*) in contaminated areas ranged from 0.0-0.1 ppm. Cadmium levels for clapper rails in this study were consistently within the published ranges for other avian species collected from non-contaminated areas (0.00-1.52 ppm, this study). On average, cadmium was higher in adult rails than HY birds. Birds collected in the NRW had higher levels on average than individuals collected in the LSJW.

Avian chromium levels

Chromium values for avian species ranged from 0.00-2.145 ppm. Birds collected within reference sites were typically much lower than this range (0.00-0.16 ppm). Birds from known contaminated sites had values within the range of 0.00-0.45 ppm. Several HY birds from this study had chromium levels consistent with published ranges for other avian species; however, all adult rails had chromium values that were substantially elevated (25.30-50.13 ppm, this study). Within this study, adults were approximately four times greater than HY birds. Chromium levels were also higher in the LSJW than the NRW.

Avian copper levels

Copper values varied greatly across avian species (not detected to 30.0 ppm in black vulture plasma). Captive psittacine plasma levels ranged from 0.124-0.142 ppm. Birds collected from reference sites ranged from 0.22-6.5 ppm, while birds collected from known contaminated areas ranged from 0.01-4.58. Copper levels in clapper rails from this study were within other published ranges, but tended to be much higher than other species. Species with similar values included tree swallow (*Tachycineta bicolor*), mourning dove (*Zenaida macroura*), and black vulture. Adult rails on average had higher values than HY birds, although one HY bird had the second highest copper value in the study (11.24 ppm). Birds collected in the NRW had higher copper levels than those collected in the LSJW.

Avian lead levels

Avian lead levels varied considerably throughout the literature from not detected to 81.5 ppm for spectacled eiders (*Somateria fischeri*) that were found moribund or dead. Normal environmental background levels are generally considered to range between 0.1-0.2 ppm. Birds that were sampled from reference sites were typically reflective of this background range; however, one value was 2.3 ppm for tundra swans (*Cygnus columbianus*). Birds collected from known contaminated areas were usually elevated above normal background levels, and sometimes were greater than 10 ppm (mallard and California condor (*Gymnogyps californianus*)). Exact levels vary per species, but blood lead levels are usually considered elevated at 0.2-0.5 ppm. Lead levels are considered toxic at levels equal to or greater than 0.5 ppm. Blood lead levels greater than 5 ppm can be considered ‘compatible with death’ for certain avian orders, such as the Falconiformes. Average lead levels for adult rails in this study were higher than HY birds, and were higher than the toxic threshold of 0.5 ppm. One adult rail had a severely elevated blood lead level, at 8.02 ppm. HY birds on average were slightly elevated above normal background levels, and some were above the toxic threshold of 0.5 ppm (0.33 mean, this study). The LSJW had approximately a ten-fold increase in average lead levels than the NRW.

Avian mercury levels

Mercury levels also varied considerably throughout the literature; values ranged from not detected to 16 ppm, for black-crowned night herons. Mercury values tended to be highest in fish-eating and insectivorous birds. Levels in birds collected from reference sites ranged from not detected to less than 1 ppm. Birds in contaminated areas demonstrated higher levels, ranging from 0.01 to 6.00 ppm. Low-risk blood mercury values are generally considered to be less than 0.7 ppm, while moderate risk is 0.7-2.9 ppm, and levels greater than 2.9 are considered high risk. However, abnormal feather growth has been documented in birds with levels as low as 0.64 ppm (Eisler, 1981). Birds fed diets containing mercury (0.75-1.5 ppm) had blood mercury levels ranging from 0.5-14 ppm. Adult clapper rails in this study were higher on average than HY birds, and both groups were considered below the low-risk threshold of 0.7 ppm. Rails collected from both watersheds were similar in average mercury concentrations and ranges in this study.

Avian nickel levels

Nickel concentrations in the literature ranged from 0.00-1.7 ppm. Levels from reference sites and contaminated sites exhibited some variability, and ranged from 0.00-1.7 ppm, and 0.00-1.2 ppm, respectively. Clapper rails from this study had some of the highest blood nickel concentrations relative to other avian species. In this study, HY clapper rails had higher average nickel levels than the adult rails. Rails captured in the LSJW had values approximately five times greater than those captured in the NRW.

Avian silver levels

I was unable to locate published whole-blood silver concentrations for avian species. The clapper rails in this study ranged from 0.00-39.27 ppm. Adult and HY clapper rail silver levels were consistent with each other, with the exception of one adult rail (39.27 ppm). Birds sampled in the LSJW had higher levels on average than those sampled in the NRW.

Avian zinc levels

Zinc levels across avian species ranged from 0.00-24.0 ppm. Birds sampled from both reference and contaminated sites exhibited variation in zinc levels, ranging from 1.74-16 ppm, and 0.0-24.0 ppm respectively. Blood zinc levels of greater than 2 ppm can be considered diagnostic of zinc toxicosis in the presence of clinical signs (Merck Veterinary Online Manual, 2016). A blue-and-gold macaw (*Ara ararauna*) was diagnosed with zinc toxicosis with a plasma zinc level of 15.5 ppm. Several of the HY clapper rails collected in this study exhibited blood zinc levels less than diagnostic threshold of 2 ppm. However, several of the adult and HY rails sampled in this study had values which were the highest found compared to published literature values. HY rails had slightly higher average values than the adult rails, and rails collected in the LSJW had much higher values than those collected in the NRW.

Clapper rail CBC and biochemistry measurements

Due to the smaller mass of the HY birds (and thus limited blood volume able to be collected), complete measurements for CBC and biochemistry panels were not obtained for all birds in this study. Additionally, complete measurements for CBC and biochemistry panels for several adults were not obtained due to insufficient plasma quantities. As far as the author is aware, published reference ranges for CBC and biochemical values are not available for clapper rails. The most closely related available species, the Guam rail (*Gallirallus owstoni*), and other members of the order Gruiformes are presented as surrogates for comparison.

All parameters measured in the CBC profile were consistent with the species presented for comparison in this study, and other crane species (Tully et al., 2000), with the exception of certain leukocyte parameters. Average leukocyte counts (WBC x $10^{3/}$µl) for clapper rails in this study were similar to the average counts of other species in Tables 3.2-3.4, but clapper rails in this study did range higher than other avian species in the literature (Hawkey and Samour, 2008; Samours, 2006; Tully et al., 2000). Eosinophil measurements in clapper rails were higher than other avian reference ranges and crane species (Hawkey and Samour, 2008; Tully et al., 2000), but this observation was also noted in the Guam rail.

Biochemistry values for clapper rails in this study were consistent in general with published reference ranges for psittacines, passerines, cranes, and members of the order Gruiformes presented in Tables 3.5-3.7, with the exception of a few parameters (Howlet, 2008; Samours, 2006; Tully et al., 2000). Aspartate aminotransferase (AST U/L) levels for clapper rails in this study were elevated compared to values in the literature and other species in Tables 3.5-3.7; although Guam rails also had elevated levels compared to other avian species (Howlet, 2008; Tully et al., 2000). Calcium values for clapper rails were consistent with other literature values and crane species, but were lower than Guam rails which appeared to have higher levels (Howlet, 2008). Blood urea nitrogen (BUN) values of clapper rails were elevated compared to other avian values (Howlet, 2008). CPK values were elevated compared to other avian species, but this observation was also noted in the Guam rail, Florida sandhill crane, and whooping crane. Both Guam rails and clapper rails had elevated uric acid levels, although clapper rails were elevated to a larger degree (Tully et al., 2000).

Invertebrate metals levels

A total of 28 composite invertebrate samples were collected over both seasons (11 in 2015, 17 in 2016). Summarized metal levels by crustaceans, mollusks, and crustaceans/mollusks composite samples are presented in Table 3.8. Due to manner of sample collection in this study (i.e. composite samples) crustacean composite samples are compared to published values of metals from Uca and Sesarma genera, mollusk composite samples are compared to published values of metals from Ilyanassa and Littorina genera, and crustacean/mollusk composites are compared to Uca, Sesarma, Ilyanassa, and Littorina genera combined (Appendix H, Table H.9).

Invertebrate arsenic levels

Composite crustaceans had levels of arsenic much higher than samples from the same genus (high range= 239.24 ppm versus 32.6 ppm, respectively), although whole body comparisons were not available for direct comparison. Composite mollusks from this study also had the highest levels of arsenic compared to other samples from the same genus (high range=153.54 ppm versus 73.0 ppm, respectively); however, only soft tissues were available for comparison. Crustacean/mollusk composite samples were within ranges and mean published values for other similar organisms, but again, whole tissue comparisons were not available.

Invertebrate cadmium levels

Cadmium concentrations in composite crustaceans from this study were relatively low (range= below detection limits-4.29 ppm) when compared to other values in the literature. For composite mollusks, cadmium concentrations were also low (range=0.15-2.43 ppm) compared to other literature values, which ranged up to 210 ppm. Crustacean/mollusk composite samples were again relatively low (range=0.27-1.36 ppm) compared to other samples, which ranged up to 210 ppm.

Invertebrate chromium levels

Chromium concentrations in composite crustacean samples were much higher than available literature values (range=2.92-68.61 ppm, this study), but only soft parts were available for comparison. Mollusk composite samples were also much higher than available literature values (range=2.34-100.44, this study), but soft parts were the only tissue type available for comparison. Crustacean/mollusk composite samples followed the same pattern as the two previous samples, and were higher than other available ranges (range=1.09-35.19 ppm, this study).

Invertebrate copper levels

Copper concentrations in composite crustacean samples were higher than other available ranges, although soft tissues from Fiddler crabs (*Uca pugnax*) collected from a contaminated area were near these levels (mean=653.57 ppm this study, versus 639.7 ppm). Mollusk composite samples in this study were also much higher than published concentrations (range=24.03-1105.95 ppm), but no whole-body specimens were available for comparison. Crustacean/mollusk composite samples from this study were within ranges of other organisms of the same genera (range=2.37-130.26 ppm).

Invertebrate lead levels

Lead concentrations in composite crustacean samples from this study were within the ranges of published values (range=0.78-19.81 ppm), and were much lower than both fiddler crabs and marsh crabs (*Sesarma erythodatyla*) collected from contaminated areas (129 ppm, 193 ppm, respectively). Composite mollusk samples were also within the ranges of previously reported values (range=0.76-10.04 ppm). Crustacean/mollusk composite samples from this study were generally much lower than other values in the literature.

Invertebrate mercury levels

Mercury values in composite crustaceans from this study were within values from the literature (range=0.04-0.4 ppm, multiple studies). Mollusk samples from this study also followed the same trend, and were also within published values, although no other whole-body comparisons were available. Crustacean/mollusk composite samples were within the range of other taxonomically similar species (range=0.04-2.6, multiple studies).

Invertebrate nickel levels

Nickel concentrations for comparable genera were not available in the literature for composite crustaceans collected in this study. Composite crustacean nickel levels in this study ranged from 1.29-19.73 ppm. Mollusk samples from this study were higher than similar species, and ranged from 6.42-19.85 ppm; however, whole body comparisons were not available. Crustacean/mollusk composite samples were also elevated compared to other similar values in the literature, but only soft tissues were available for comparison.

Invertebrate silver levels

Silver concentrations for comparable genera were not available in the literature for composite crustaceans collected in this study. Concentrations of mollusk composite samples collected in this study were within other published values, and ranged from 0.55-16.2 ppm. Crustacean/mollusk composite samples were lower than all other available published values, and ranged from 0.18-0.85 ppm. Contaminated sites had values ranging from 3.1-17.4 ppm.

Invertebrate zinc levels

Zinc values in composite crustaceans collected in this study were very elevated compared to other similar crustacean species (range=19.38-929.09 ppm, this study versus 0.65-403 ppm, multiple studies). However, composite mollusk samples did not exhibit this pattern; in general, samples from this study were lower than other published values (range=8.1-184.1 ppm, this study versus 2.6-2,153 ppm, multiple studies).

Discussion

Avian metal levels

All birds in this study appeared healthy at the time of capture; no outward signs of disease or injury were noted. As mentioned previously, metals are associated with a variety of adverse effects. Also, metal concentrations in all organisms can vary tremendously by tissue type, species, age, sex, geographic location, temporally, trophic level (diet and foraging habitats), interactions with other metals (i.e. nutritional deficiencies of essential elements), underlying physical status, and by many other factors, which can confound the interpretation of metal levels (Eisler, 1985; Goyer, 1995; Hargreaves et al., 2011; Kaminski et al., 2007; Lane et al., 2011; Meyer et al., 2011; Rosenthal et al., 2005; Sanchez-Virosta et al., 2015). Because there is a dearth of information for several metals in this study, and specifically metal levels in clapper rails, results should be interpreted with caution due to these factors.

Avian arsenic levels

In general, arsenic concentrations are typically <1.0 mg/kg (equivalent to ppm) in most living organisms, but are elevated in marine organisms (Eisler, 1988a). Findings in the literature regarding arsenic concentrations vary: higher arsenic concentrations have been found in invertebrate samples collected in coastal areas; however, semi-palmated plovers (*Charadrius semipalmatus*) foraging on these invertebrates did not exhibit higher blood levels, while body condition (mass/culmen measurements) was negatively related to arsenic concentrations in feathers for red phalaropes (*Phalaropus fulicarius*) in the same study (Hargreaves et al., 2011). Osprey (*Pandion halieatus*) chicks sampled along contaminated stretches of river corridors exhibited significantly higher blood arsenic concentrations than reference sites, and were generally reflective of arsenic concentrations in nearby sediments (Langner et al., 2012). Arsenic levels for birds within this study were much higher than other published values; however, the author was unable to locate published threshold effects for arsenic concentrations in bird blood.

Avian cadmium levels

Cadmium values for clapper rails in this study were within the range of other avian values, although some values were elevated. Both hemoglobin concentrations and hematocrit levels in pied flycatchers were negatively correlated with cadmium levels much lower than observed in this study (Berglund and Nyholm, 2011), but no adverse effects were demonstrated on apparent survival in two species of sea ducks (Wayland et al., 2008) with comparable levels. HY birds in this study generally had lower levels than adults, and similar results have been documented in common buzzards (*Buteo buteo*) (Carneiro et al., 2014). It appears birds and mammals have some degree of resistance to cadmium toxicity, but general recommendations for cadmium limits include no more than 5 ppm whole animal fresh weight (Eisler, 1985). None of the birds in this study exceeded this recommendation, but the same tissue types were not available for direct comparison. Other factors to consider when assessing cadmium toxicity is that cadmium has an affinity for liver and kidney tissues, so blood may not be the most appropriate medium to assess exposure (Carneiro et al., 2014; Eisler, 1985).

Avian chromium levels

There are few studies on the effects of chromium in wild birds, but birds can accumulate chromium in feathers and other tissues (Sparling, 2016). Additionally, other studies have demonstrated substantial individual variation in chromium levels in feathers of colonial seabirds (Burger and Gochfeld, 2016). Chromium levels in clapper rails from this study were much higher than published reference ranges, but another point to consider is that this study quantified total chromium levels which does not distinguish between the elemental form of Cr^{0}, the less toxic trivalent form, Cr^{+3}, and the severely toxic form Cr^{+6} (Eisler, 1986).

Avian copper levels

Copper values for clapper rails varied substantially; some values were within published ranges for avian species, and some were much higher. Increases in tissue copper levels has been documented in birds near heavily contaminated areas (Berglund and Nyholm, 2011; Langner et al., 2012), so this may be reflective of local conditions. Song sparrows (*Melospiza melodia*) with blood copper levels up to 1.118 ppm were not found to have any adverse effects (Lester and Van Riper, 2014). Copper concentrations can also vary temporally and with age; osprey levels varied depending on the season of collection, while the juveniles of several species of marine birds had higher levels than adults (Eisler, 2010b). This may partially explain the large range of copper values seen in this study. Copper is an essential element involved in many enzyme functions, so it is easily taken up by organisms, and toxicity can result due to deficiencies or exceedance of normal levels (Sparling, 2016). As is the case with cadmium, birds and mammals are tolerant to high levels of copper (Eisler, 1998a), and it is not likely for mortality to result unless extremely high environmental concentrations are present (Sparling, 2016).

Avian lead levels

Lead values of clapper rails were within published ranges of other avian species; however, there were several birds which were elevated above the normal background levels of <0.2 ppm, several within known toxic ranges of >0.2-11.0 ppm, and one with a severely elevated level, typically associated with mortality events at > 5 ppm (Eisler, 1988b; Eisler, 2010b; Franson, 1996; Friend and Franson, 1999). There are varying degrees of susceptibility to lead poisoning in birds based on species; adverse effects in birds can be seen at levels > 0.2 ppm (Franson, 1996). For example, a bald eagle collected by the Southeastern Cooperative Wildlife Disease Study died of lead toxicosis at a blood concentration of 0.46 ppm. One potential explanation for the elevated levels seen in this study may be the ingestion of lead shot; mortality due to the ingestion of lead pellets in coots and rails is commonly reported (Friend and Franson, 1999). This may potentially explain the abnormally high concentration seen in an adult rail in this study (8.02 ppm). Sub-lethal effects such as changes in immune function, enzyme activity, and reproductive output have been found at levels as low or lower than 0.5 ppm (Bannon et al., 2011;

Berglund and Nyholm, 2011; McQuiston, 2002); but this was not documented in certain species of seabirds (Summers et al., 2014). Clapper rails may be experiencing sub-lethal effects at these levels, but more research is needed.

Avian mercury levels

The deleterious effects of mercury are well documented across several taxa, and it is widely regarded as a non-essential element which should be monitored because of its ability to biomagnify and potential to convert to methyl mercury, an extremely toxic form, in aquatic environments (Eisler, 1987; Sparling, 2016). Factors that affect mercury levels are related to diet and location, with birds that consume fish in aquatic habitats typically having higher metal burdens (Eagles-Smith et al., 2009; Eisler, 2010b; Friend and Franson, 1999; Lane et al., 2011; Langner et al., 2012; Thompson, 1996). Mercury values for clapper rails were within published values for avian species, and often much lower. General risk categories for low (<1 ppm), moderate (1-3 ppm), and high (>3 ppm) mercury levels in blood have been developed based on studies in common loons (*Gavia immer)* and all birds in this study were within the low risk category (Evers et al., 2008). Other factors to consider when evaluating mercury levels are body condition, reproductive stage, and molt stage, as these can alter blood levels (Ackerman et al., 2011; Ackerman et al., 2008; Sepulveda et al., 1999). Mercury is the one metal in this study for which blood values from other clapper rails exist. California clapper rails (*Rallus longirostris obsoletus*) collected in San Francisco Bay area had blood mercury levels ranging from 0.15-1.43 ppm, and these values were negatively associated with body condition (Ackerman et al., 2012). Clapper rails collected in this study were well within this range, and did not appear to be in poor body condition.

Avian nickel levels

Nickel levels in the available literature were much lower than what was observed in this study; however, blood nickel concentrations were also elevated in coastal areas and ponds in Arctic shorebirds, so this may be a reflection of marsh areas in general (Hargreaves et al., 2011). Nickel levels in other bird tissues collected near contaminated areas such as nickel smelters tend to be elevated as well (Eisler, 2010b), but it does not appear that nickel bio accumulates in the food chain (Eisler, 1998b). It is unclear if these levels are associated with adverse effects in clapper rails.

Avian silver levels

As mentioned previously, the author was unable to locate any published values for whole blood silver concentrations in birds. As such, it is not clear what the findings in this study represent, although it is noteworthy that one adult had a substantially elevated silver level relative to other birds in this study.

Avian zinc levels

Zinc concentrations in clapper rails in this study varied greatly; most values were within ranges documented in other avian species, while some were higher than any published values. Documented zinc toxicosis was observed in a blue-and-gold macaw with a plasma zinc level of 15.5 ppm; several clapper rails were nearly three times this amount. The higher values found in this study are most consistent with samples collected from contaminated areas; however, zinc concentrations in organisms vary considerably and can be difficult to interpret (Eisler, 1993). One reason for this is that zinc is an essential element, and is required by all living organisms (Sparling, 2016). Another potential difficulty in interpreting zinc levels is that they can vary in a relatively short time frame; zinc levels in various psittacine species were found to change diurnally (Rosenthal et al., 2005). It appears that seabirds, marsh birds, and birds near zinc-contaminated areas may have higher concentrations than their terrestrial counterparts (Eisler, 2010b). This may partially explain the higher values noted in this study; areas near the Preserve have had high zinc concentrations in sediments (Anderson et al., 2005).

Clapper rail CBC and biochemistry measurements

CBC and biochemistry values were unremarkable and consistent with other taxonomically similar species, with the exception of a few parameters. WBC counts, eosinophil counts, AST, BUN, uric acid, and CPK levels were elevated compared to reference ranges in the literature. Increased WBC counts are observed in cases of stress, infection, inflammation, and neoplasia. There were two clapper rails in this study which had a greater than double the normal range of WBC counts, which can be indicative of some underlying disease process. Eosinophils were also elevated for clapper rails in this study, but this was also seen in Guam rails. Increases in the percentage of eosinophils can result from parasite burdens, or allergic responses (Howlet, 2008). Causes for elevated AST levels include muscle damage or liver dysfunction, but this value needs to be taken in context with creatinine kinase levels, since it is a non-liver specific enzyme, and muscle damage alone can cause elevations. Elevated BUN in birds is potentially associated with dehydration, while increased uric acid levels are associated with renal dysfunction in birds (Harr, 2006). The source of CPK in the body is various muscle types, and elevation can occur with disruption to these tissues, physical capture, and lead toxicity (Harr, 2006; Howlet, 2008). Age is also a factor which can affect these parameters as well (Harr, 2006).

Invertebrate arsenic levels

Arsenic concentrations are elevated in marine organisms; however, the form of arsenic that occurs in these organisms is arsenobetaine, which is not toxic to consumers (Eisler, 1988a). Concentrations of arsenic can vary by species and also the type of tissue analyzed; however, mollusks and crustaceans are known to have especially high concentrations, which appears to be related to their ability to accumulate arsenic from seawater (Eisler, 2010a). Concentrations of more than 100 mg/kg DW have been found in marine crustaceans (Eisler, 1988a), and the results from this study are consistent with this finding.

Invertebrate cadmium levels

Cadmium concentrations also appear to be higher in marine organisms, and this is probably a function of increased cadmium levels in seawater (Eisler, 1985). Additionally, cadmium levels are higher near point sources, especially in mollusk tissues (Eisler, 1985; Eisler, 2010a). Other sources state that cadmium levels in aquatic organisms are typically less than 5mg/kg, and all of the values in this study were within this range (Sparling, 2016).

Invertebrate chromium levels

Increased chromium levels are associated with increasing proximity to point sources, and the highest chromium levels are observed in the lowest trophic organisms (Eisler, 1986; Sparling, 2016). Mollusks in particular can accumulate high chromium levels; this may partially explain why the composite mollusk samples in this study were elevated (Eisler, 2010a). Another potential explanation for the high levels seen in this study is that exposure to chromium may also be higher to benthic invertebrates, since chromium binds to the sediment particles in which these organisms live (Eisler, 2010a; Sparling, 2016). The study area does have a history of elevated chromium levels near the Preserve, which may be a source for benthic invertebrates.

Invertebrate copper levels

Copper levels of invertebrates were fairly high in this study; this may partially due to the fact that mollusks can accumulate copper from seawater, and thus exhibit copper levels higher than other organisms (Eisler, 2010a). Elevated copper levels in marine organisms are also documented in areas that are near industrial, agricultural, or other point sources, such as domestic wastewater (Eisler, 2010a; Sparling, 2016). This may be a relevant factor in this study, as copper water levels near the Preserve have been elevated. Also, copper levels can vary substantially based on type of organism, development stage, hydrologic characteristics, and other factors as well (Eisler, 2010a).

Invertebrate lead levels

Lead concentrations are correlated with the degree of anthropogenic sources on the landscape (Eisler, 2010a), and aquatic invertebrates near contaminated sites can reach extraordinarily high levels (Sparling, 2016). Organisms that forage near mining areas, roads, and other industrial sites may be at risk for increased bioaccumulation of lead (Eisler, 1988b). The invertebrate values from this study are within other published ranges, despite areas around the Preserve exceeding lead quality standards for sediment and surface waters.

Invertebrate mercury levels

The mercury concentrations of invertebrates in this study were within published ranges and tended to be low. One concern with mercury is that organisms can absorb it from seawater, and either transfer it to upper trophic levels via biomagnification, or convert it to a more toxic form, such as methyl mercury (Eisler, 1987; Eisler, 2010a). Mercury levels in surface waters around the Preserve have had elevated levels in the past, so this may potentially be a concern in the future.

Invertebrate nickel levels

Nickel concentrations for the invertebrate genera collected in this study were not widely available; the results from this study were higher than published values. Additionally, the types of tissues available for comparison (i.e. soft parts) were different from the tissues collected in this study, whole body. Nickel concentrations can vary in marine mollusks and crustaceans based on tissue type, season, location, variable bioconcentrations factors of individual species (Eisler, 2010a). As such, these results should be interpreted with caution.

Invertebrate silver levels

Silver concentrations for the invertebrates collected in this study were also not widely available; but were either within the range or lower than published literature values. Elevated silver levels in seafood are associated with areas near industrial sources and sewer outfalls (Eisler, 1996). Silver can be toxic to aquatic organisms, but its effects on other wildlife species are not known (Eisler, 1996; Eisler, 2010a).

Invertebrate zinc levels

Zinc is an essential element, and is required by organisms for various enzymatic activities (Sparling, 2016). Zinc is present in all crustacean species, and often at elevated levels, particularly in species such as barnacles and oysters, which filter feed (Eisler, 2010a). Elevated levels are seen near zinc contaminated areas, and even reference sites (Eisler, 2010a; Sparling, 2016). In humans, ingestion of seafood with high zinc levels probably does not cause significant health threats (Eisler, 2010a). Crustacean samples from this study were higher than other published values from the same genera, but zinc concentrations can be > 4 g/kg in bivalve mollusks and barnacles; additionally, there were multiple different tissue types used in comparison, so this should be taken into account as well.

Conclusion

This project was designed as an exploratory study; many of the contaminants and health parameters analyzed in this study had not previously reported in whole blood samples for clapper rails. As such, this makes interpretation of results challenging, since there are essentially no set standards available for comparison. Standard reference materials for heavy metals were not available at the time of analysis, so specific rates of recovery for the metals analyzed in this study are not available. Additionally, the sample size for this project was limited (N=15), and arguably, some of these individuals are not independent, since they were collected from the same brood. Further, in order to quantitatively assess the risk of HATMC to clapper rail health, analysis of specific prey items and tissue types would be in order. The fact that there were several birds that exhibited metal levels that were orders of magnitude higher than many other species in the literature does warrant further investigation. Lead levels for several birds in this study were at levels known to cause adverse effects in birds. Several other metals in this study were also elevated relative to other available ranges, but the effects of these levels are not understood. The collection of additional samples (i.e. feathers, eggs, other biomarkers, water and sediment levels) could potentially elucidate the effects of these metals on clapper rail health, and potentially serve as a proxy for other marsh inhabitants. The collection of both juveniles and adults could facilitate an understanding of the effects of age and site location on metal levels in clapper rails. This study can provide a starting point for future work in this area, since HATMC will likely increase as a function of increasing urbanization around the Preserve.

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Table 3.1. Mean, range, standard deviation (SD), and sample size (N) of whole blood -heavy metal values for adult, HY, and watershed of wild clapper rails (*Rallus crepitans*) captured in this study in parts per million (ppm).

	Adult clapper rails			**HY clapper rails**			**Clapper rails by LSJW**			**Clapper rails by NRW**		
Parameter	**Mean (N=6)**	**Range**	**SD**	**Mean (N=9)**	**Range**	**SD**	**Mean (N=9)**	**Range**	**SD**	**Mean (N=6)**	**Range**	**SD**
Arsenic	6.32	0.05-15.51	4.90	4.61	1.02-11.03	3.90	5.62	1.02-11.03	3.66	4.82	0.05-15.51	5.30
Cadmium	0.52	0.05-1.52	0.67	0.20	0.00-0.55	0.17	0.16	0.05-0.55	0.17	0.58	0.00-1.52	0.64
Chromium	34.44	25.30-50.13	8.50	8.50	0.54-25.11	10.59	21.77	0.54-50.13	16.93	14.55	0.93-31.63	13.53
Copper	4.98	1.26-14.57	4.43	3.70	0.55-11.24	3.32	3.94	0.64-11.24	3.25	4.61	0.55-14.57	4.58
Lead	1.39	0.03-8.02	2.97	0.33	0.00-1.04	0.34	1.18	0.00-8.02	2.45	0.12	0.03-0.33	0.10
Mercury	0.39	0.04-0.79	0.27	0.12	0.00-0.21	0.06	0.23	0.06-0.62	0.18	0.22	0.00-0.79	0.27
Nickel	0.36	0.13-0.61	0.16	2.26	0.19-8.70	2.72	2.22	0.19-8.70	2.74	0.42	0.13-0.88	0.25
Silver	6.74	0.03-39.27	14.55	0.02	0.00-0.05	0.02	4.50	0.01-39.27	12.30	0.03	0.00-0.07	0.02
Zinc	17.57	5.64-50.65	15.19	18.52	0.00-56.93	23.63	26.53	0.048-56.93	22.89	5.54	0.00-13.58	4.35

Table 3.2. Mean, range, standard deviation (SD), and sample size (N) of complete blood counts of wild clapper rails (*Rallus crepitans*) captured in this study.

Parameter	**N**	**Mean**	**Range**	**SD**
WBC x $10^{3/}$ µl	8	16.3	6.2-39.0	10.6
PCV %	8	34.4	36.0-41.0	1.4
Heterophils %	8	28.2	17.0-53.0	14.3
Absolute Heterophils/ µl	8	4.5	1.3-9.0	2.3
Lymphocyte %	8	41.6	26.0-65.0	12.2
Absolute Lymphocyte/ µl	8	7.3	3.3-18.0	5.1
Monocytes %	7	1.1	0.0-3.0	1.2
Absolute Monocytes / µl	7	0.2	0.0-0.9	0.3
Basophils %	4	1.1	0.0-5.0	1.7
Absolute Basophils / µl	4	0.2	0.1-0.7	0.2
Eosinophils %	4	14.6	12.0-54.0	16.3
Absolute Eosinophils/ µl	4	3.4	1.4-16.4	6.2

Table 3.3. Mean, range, standard deviation (SD), and sample size (N) of complete blood counts of Guam rail (*Gallirallus owstoni*), Fontenot et al., 2006.

Parameter	N	Mean	Range	SD
WBC x $10^{3/}$ µl	155	3.9	0.4-15.4	3.1
PCV %	155	45.0	24.0-54.0	4.7
Heterophils %	155	32.8	4.0-86.0	16.0
Absolute Heterophils/ µl	155	1.2	0.0-6.2	1.1
Lymphocyte %	155	50.0	7.0-88.0	16.8
Absolute Lymphocyte/ µl	155	2.0	0.0-8.8	1.9
Monocytes %	155	6.1	0.0-31.0	5.6
Absolute Monocytes / µl	155	0.3	0.0-1.7	0.4
Basophils %	155	2.3	0.0-16.0	3.1
Absolute Basophils / µl	155	0.1	0.0-0.6	0.1
Eosinophils %	155	8.6	0.0-29.0	6.9
Absolute Eosinophils/ µl	155	0.3	0.0-3.2	0.5

Table 3.4. Mean and sample size (N) of complete blood counts of Florida sandhill crane (*Grus canadensis pratensis*), Greater sandhill crane (*Grus canadensis*), and Whooping crane (*Grus americana*), Olsen et al., 2001. 'NM' is not measured.

	Florida sandhill crane		**Greater sandhill crane**		**Whooping crane**	
Parameter	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
WBC x $10^{3/}$ µl	50	12.0	30	9.6	40	14.5
PCV %	50	36.9	30	39.1	40	39.6
Heterophils %	50	66.4	33	64.1	40	63.7
Absolute Heterophils/ µl	NM	NM	NM	NM	NM	NM
Lymphocyte %	50	31.1	33	34.2	40	32.3
Absolute Lymphocyte/ µl	NM	NM	NM	NM	NM	NM
Monocytes %	50	1.0	33	0.5	40	1.2
Absolute Monocytes / µl	NM	NM	NM	NM	NM	NM
Basophils %	NM	NM	NM	NM	NM	NM
Absolute Basophils / µl	NM	NM	NM	NM	NM	NM
Eosinophils %	50	1.3	33	1.2	40	2.6
Absolute Eosinophils/ µl	NM	NM	NM	NM	NM	NM

Table 3.5. Mean, range, standard deviation (SD), and sample size (N) of biochemistry values of wild clapper rails (*Rallus crepitans*) captured in this study.

Parameter	**N**	**Mean**	**Range**	**SD**
AST (U/L)	8	600	273-979	266.6
TP (g/dL)	5	3.8	3.3-5.1	0.6
Calcium (mg/dL)	4	10.0	9.1-10.4	0.5
Phosphorus (mg/dL)	4	4.8	2.7-7.0	2.0
BUN (mg/dL)	5	7.4	4-13	3.0
Glucose (mg/dL)	2	233	217-248	15.5
Cholesterol (mg/dL)	3	155	130-176	19.1
Triglycerides (mg/dL)	3	55	51-57	2.6
Magnesium (mg/dL)	2	3.7	3.1-4.3	0.6
GGT (U/L)	2	8	7-8	0.5
CPK (U/L)	2	1037	805-1269	232.0
Sodium (mEq/L)	4	153	149-160	4.2
Potassium (mEq/L)	4	2.2	1.5-2.7	0.6
Chloride (mEq/L)	4	118	115-122	2.5
TCO2 mEq/L	4	16	13-18	2.0
Anion Gap (mEq/L)	4	20.7	16.5-26.7	3.8
Uric acid (mg/dL)	6	13.7	0.1-18.9	6.6

Table 3.6. Mean, range, standard deviation (SD), and sample size (N) of biochemistry values of Guam rail (*Gallirallus owstoni*), Fontenot et al., 2006. 'NM' is not measured.

Parameter	N	Mean	Range	SD
AST (U/L)	155	232	11-615	101.0
TP (g/dL)	155	4.1	3.2-6.6	0.7
Calcium (mg/dL)	155	12.2	8.8-11.4	4.9
Phosphorus (mg/dL)	155	3.5	0.6-9.1	2.1
BUN (mg/dL)	155	NM	NM	NM
Glucose (mg/dL)	155	276	3-867	127.0
Cholesterol (mg/dL)	155	227	170-272	27
Triglycerides (mg/dL)	155	NM	NM	NM
Magnesium (mg/dL)	155	NM	NM	NM
GGT (U/L)	155	NM	NM	NM
CPK (U/L)	155	719	191-6912	1047
Sodium (mEq/L)	155	253	159-1563	349
Potassium (mEq/L)	155	1.8	1.2-4.2	0.8
Chloride (mEq/L)	155	120	114-131	6
TCO2 mEq/L	155	NM	NM	NM
Anion Gap (mEq/L)	155	NM	NM	NM
Uric acid (mg/dL)	155	5.7	2.5-13.8	2.5

Table 3.7. Mean and sample size (N) of biochemistry values of Florida sandhill crane (*Grus canadensis pratensis*) and Greater sandhill crane (*Grus canadensis*), Olsen et al., 2001. 'NM' is not measured.

	Florida sandhill crane			Greater sandhill crane		
Parameter	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
AST (U/L)	50	196	53	33	195	39
TP (g/dL)	50	3.0	0.4	33	3.0	0.4
Calcium (mg/dL)	50	9.96	0.9	33	9.19	0.73
Phosphorus (mg/dL)	50	4.12	1.52	33	3.65	1.68
BUN (mg/dL)	NM	NM	NM	NM	NM	NM
Glucose (mg/dL)	50	252	24	33	248	34
Cholesterol (mg/dL)	NM	NM	NM	NM	NM	NM
Triglycerides (mg/dL)	NM	NM	NM	NM	NM	NM
Magnesium (mg/dL)	NM	NM	NM	NM	NM	NM
GGT (U/L)	NM	NM	NM	NM	NM	NM
CPK (U/L)	49	1784.0	2171	30	284	129
Sodium (mEq/L)	NM	NM	NM	NM	NM	NM
Potassium (mEq/L)	NM	NM	NM	NM	NM	NM
Chloride (mEq/L)	NM	NM	NM	NM	NM	NM
TCO2 mEq/L	NM	NM	NM	NM	NM	NM
Anion Gap (mEq/L)	NM	NM	NM	NM	NM	NM
Uric acid (mg/dL)	50	9.49	3.13	33	6.13	2.58

Table 3.8. Mean, range, standard deviation (SD), and sample size (N) of heavy metal values for composite whole-body invertebrate samples collected in this study by taxonomic group in parts per million (ppm) dry weight. 'BDL' is below detection limits.

	Crustaceans			**Crustaceans and Mollusks**			**Mollusks**		
Parameter	**Mean (N=14)**	**Range**	**SD**	**Mean (N=7)**	**Range**	**SD**	**Mean (N=7)**	**Range**	**SD**
Arsenic	74.95	8.58-239.24	61.99	16.22	2.69-25.49	7.31	46.90	5.35-153.54	48.69
Cadmium	0.74	BDL*-4.29	1.24	0.89	0.27-1.36	0.37	0.95	0.15-2.43	0.78
Chromium	46.20	2.92-68.61	20.90	9.64	1.09-35.19	10.92	46.44	2.35-100.44	33.81
Copper	653.57	42.97-1745.81	427.76	59.84	2.37-130.26	39.11	331.77	24.03-1105.95	335.09
Lead	19.81	0.78-78.38	25.58	3.47	0.30-11.53	3.67	4.35	0.76-10.04	3.17
Mercury	0.21	0.02-0.30	0.10	0.35	0.17-0.56	0.13	0.12	0.02-0.36	0.14
Nickel	11.58	1.29-19.73	5.54	12.83	9.52-19.45	3.12	10.72	6.42-19.85	4.65
Silver	2.87	0.07-5.16	1.70	0.56	0.18-0.85	0.26	6.84	0.55-16.20	5.51
Zinc	450.67	19.38-929.09	317.11	70.31	6.21-164.03	50.64	57.21	8.10-184.10	60.65

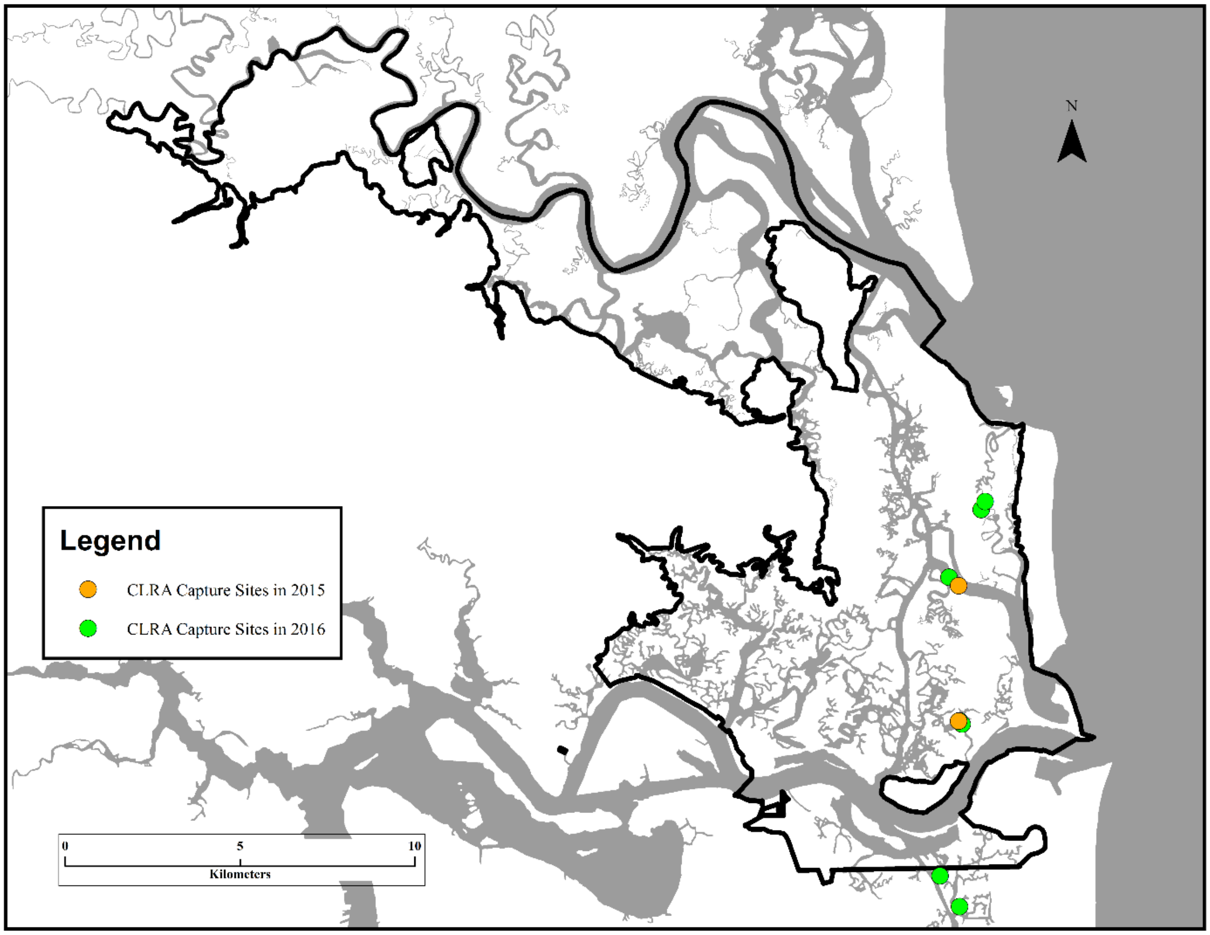

Figure 3.1. Capture locations of clapper rails collected in 2015-2016 within the Timucuan Ecological & Historic Preserve, Jacksonville, Florida.

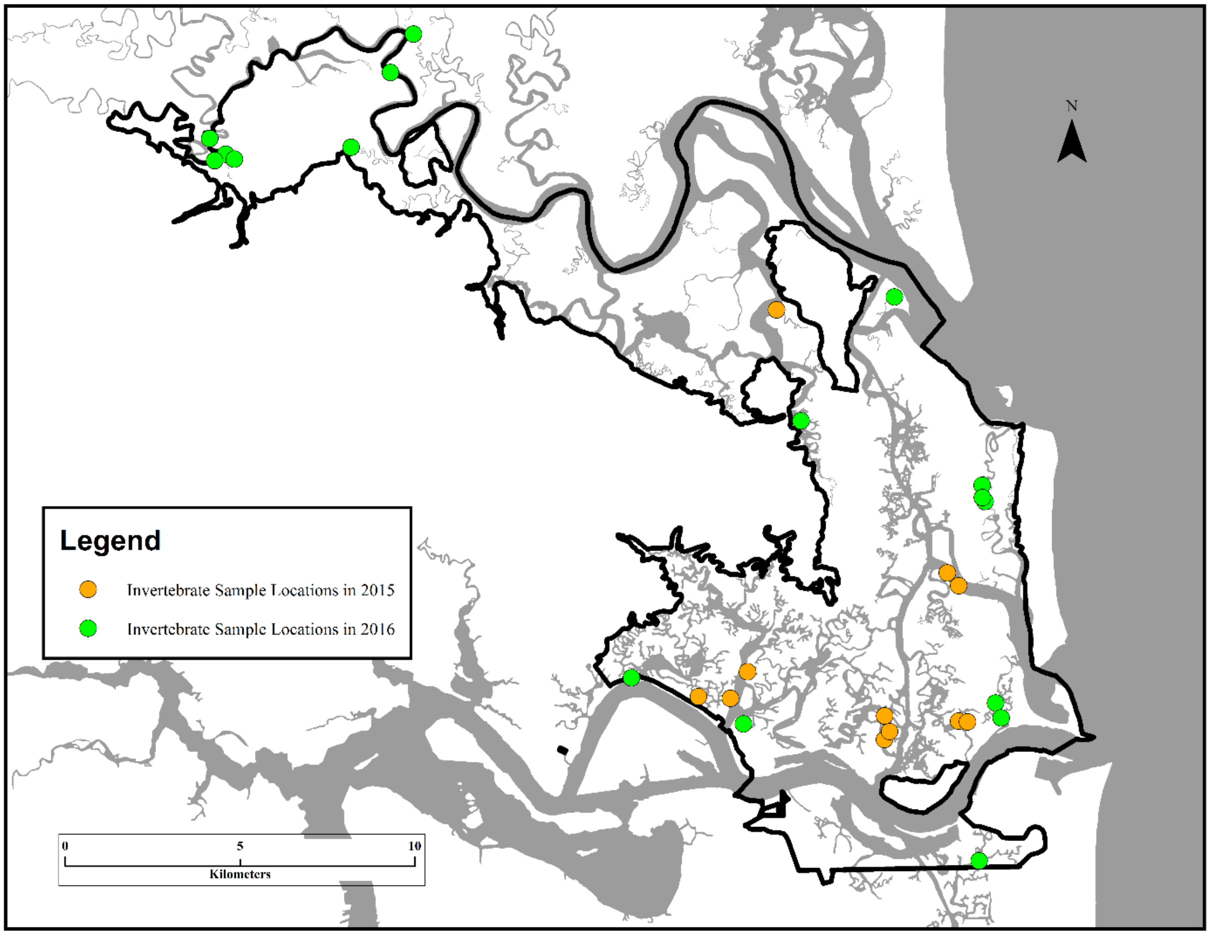

Figure 3.2. Sample locations of composite invertebrate samples collected in 2015-2016 within the Timucuan Ecological & Historic Preserve, Jacksonville, Florida.

CHAPTER 4

SUMMARY AND CONCLUSIONS

Summary and conclusions

My objectives in this project were to identify relevant variables and scales important for breeding secretive marsh birds within the Timucuan Ecological & Historic Preserve. The region around the Preserve has been altered by various land use practices (i.e. dredging of the St. Johns river, the transition from low-density residential development to high-density urban development and industry in the city of Jacksonville), and I expected a response of the avian community to these influences. Specifically, I hypothesized that landscape scale variables for the Preserve would likely be important, since the degradation and alteration of wetlands are thought to be one of the primary causes of declining marsh bird species. My goal was to establish abundance estimates for the Preserve, since baseline data and information regarding population trends specific for the Preserve are not known. Additionally, I wanted to determine if clapper rails within the Preserve exhibited heavy and trace metal contaminants in blood samples, and also to assess if these metals were associated with adverse effects on clapper rail health.

In chapter one, I analyzed various composition and configuration metrics at different scales to develop predictive models for marsh bird abundance. My research did support the inclusion of multiple scales in abundance modeling for avian species; particularly at the landscape scale. Clapper rail, marsh wren, and seaside sparrow models all included variables at the landscape scale which may be useful as a proxy to assess marsh bird response to anthropogenic influences in and around the Preserve, and other coastal areas. Both marsh wren and seaside sparrow abundance were negatively associated with land cover types other than marsh (e.g., Euclidean distance to forest, proportion of non-forested area). Metrics at the landscape level may be a method to quantify habitat quality for wetland birds in this area, and potentially other species (e.g. proportion of urban or high-density development may be a proxy for degree of contamination in these wetlands). However, there were issues which may have masked relationships in this study or generated spurious results. Low detection rates for some species, potential variability between sample locations across survey years, and issues with identifying king and clapper rails may been the source of discrepancy amongst some model results. The Standardized North American Marsh Bird Monitoring Protocol includes the use of a call-broadcast component; this could have introduced variability in some of my counts which may have affected abundance estimates. Additional exploration of the effects of call-broadcast on secretive marsh birds is necessary to quantify error associated with this method. Another possible approach to abundance modeling for the Preserve may be the use of occupancy models, since several species in this study (e.g., black rail, least bittern, common gallinule) did not have sufficient detections to allow for abundance modeling. Additionally, further work is need to assess whether or not results from certain regions are indeed generalizable, and whether occupancy versus abundance modeling is more appropriate.

In chapter two, I collected blood samples from clapper rails, and invertebrate samples which I analyzed for arsenic, cadmium, chromium, copper, lead, nickel, mercury, silver, and zinc, using inductively-coupled plasma mass spectrometry. I did not capture my intended sample size, and I had psuedoreplication since I captured multiple individuals from the same brood. However, there were several birds that exhibited certain metal levels that were at times much higher than other species in the available literature, and this warrants further investigation. Lead levels for several birds in this study were at levels known to cause adverse effects in birds. Several other metals in this study were also elevated relative to other available ranges, but the effects of these levels are not understood. These findings may be reflective of the condition and of the wetlands in the Preserve; clapper rails occupy a high trophic level within these systems, and the results from this study support the use of clapper rails as an indicator species for estuarine health. The collection of additional samples (i.e. feathers, eggs, other biomarkers, water and sediment levels, other invertebrate species) could also potentially elucidate the effects of these metals for other marsh inhabitants or humans, since this area is used for commercial fishing and shellfish harvest and recreation.

APPENDIX A: DESCRIPTION OF GIS PROCEDURES

Appendix A contains a summary of the GIS procedures used for sample location selection.

Study design and site selection

The administrative boundary of the Preserve was used as the sampling frame. A 400-meter x 400-meter grid was overlaid onto the administrative boundary using the fishnet function (ArcMap 10.3). Grid spacing was consistent with recommendations from the Standardized North American Marsh Bird Monitoring Protocol for new survey areas (Conway, 2011). High-resolution aerial photography (0.5-meter pixel, NOAA, 2011) and a navigable waterways shapefile (National Park Service) were visually inspected to determine areas where jon boat access was possible such that sample locations could be accessed regardless of tidal stage. For the 2015 season, a 75-meter buffer was placed along all navigable waterways. Points falling within the 75-meter buffer were considered potential sample locations. All surveys were conducted at the emergent marsh-water interface by jon boat. In the event that a point did not fall at this interface, (i.e. in the middle of the channel or non-marsh habitat) the closest emergent vegetation-water interface to the original point was chosen. This approach allowed for substitution of sample locations based on access issues (oyster beds, shallow waters, falling tides, sand bars, etc) and to help expedite travel time between sample locations. For the 2016 field season, all surveys were conducted by canoe with a trolling motor. A canoe with a trolling motor setup was used because a jon boat was not available. The same 400-meter x 400-meter grid was used to select potential sample locations, but sample locations for the 2016 season were completely different from those sampled in 2015, due to the type of boat used to conduct surveys. Since all surveys were done using a canoe, all potential canoe launches were first identified within the Preserve. A 1,000-meter buffer was placed around all potential canoe launch sites, since this was the maximum safe distance the survey crew could travel from a launch site. Only points within these buffers were considered as potential sample locations. In order to refine the sample location selection process, land cover data (30-meter pixel) were obtained (NOAA CCAP, 2010).

All emergent marsh from this raster data set was reclassified to 0,1 format (ArcGIS 10.3). A vector-based hydrology layer was obtained from a National Park Service 2012 saltmarsh habitat remote-sensing project. This vector layer was converted to a 1-meter pixel raster format. Euclidean distance (ArcGIS 10.3) was calculated for this raster water layer, and the resulting layer was reclassified into 0-30 meter and >30-meter distance bins. These marsh and Euclidean distance water raster layers were multiplied together to select areas that were accessible by canoe and that were at the emergent vegetation and water interface. Lastly, points from the original 400-meter x 400-meter grid within the 1000-meter buffers were intersected with the multiplied raster layer to select the final potential sample locations. Points were randomly drawn, and if two points were within the same buffer, another point was chosen in order to maximize the geographic area covered.

APPENDIX B: LIST OF CANDIDATE ABUNDANCE MODELS

Appendix B contains a list of candidate models developed for each species in this study.

Table B.1: List of candidate models and model codes for clapper rails in 2015 in this study.

Code	Model Parameterization
fm1	~julian_date+min_af_sunrise ~log(AREA_MARSH_M2)+iji_1_5000m + pland_1_5000m
fm10	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+lsi_1_400m+area_mn_1_1500m
fm11	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+MEAN_SAL_PPT+ed_1_400m
fm12	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+para_mn_1_1500m+ed_2_400m
fm13	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+pd_1_5000m+I(pd_1_5000m^2)
fm14	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+pd_1_5000m+ed_landcover_15k_urban1nd
fm15	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+pd_1_5000m+ed_landcover_15k_fornat1nd
fm2	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+pd_1_5000m+saltmarsh_spar10_mw50m
fm3	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+pd_1_5000m+saltmarsh_junc10_mw50m
fm4	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+shape_mn_1_400m+area_mn_1_1500m
fm5	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m+pland_1_5000m
fm6	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+pland_1_5000m+ed_1_5000m
fm7	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+pd_1_1500m+pland_3_5000m
fm8	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+ed_1_1500m+pland_4_5000m
fm9	~julian_date+min_af_sunrise~log(AREA_MARSH_M2)+ed_1_1500m+pd_4_5000m
null	null

Table B.2: List of candidate models and model codes for KICL in 2015 in this study.

Code	Model Parameterization
fm1	~wind~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr
fm10	~wind~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_fornat1nd
fm10NB	~wind~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_fornat1nd**
fm10ZP	~wind~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_fornat1nd*
fm11	~wind~log(AREA_MARSH_M2)+pland_4_5000m+saltmarsh_junc10_mw50m
fm11NB	~wind~log(AREA_MARSH_M2)+pland_4_5000m+saltmarsh_junc10_mw50m
fm11ZP	~wind~log(AREA_MARSH_M2)+pland_4_5000m+saltmarsh_junc10_mw50m*
fm12	~wind~log(AREA_MARSH_M2)+pland_5_5000m

Code	Model Parameterization
fm12NB	~wind~log(AREA_MARSH_M2)+pland_5_5000m**
fm12ZP	~wind~log(AREA_MARSH_M2)+pland_5_5000m*
fm1NB	~wind~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr**
fm1ZP	~wind~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr*
fm2	~wind~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m
fm2NB	~wind~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m**
fm2ZP	~wind~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m*
fm3	~wind~log(AREA_MARSH_M2)+iji_1_5000m+iji_1_5000m^2
fm3NB	~wind~log(AREA_MARSH_M2)+iji_1_5000m+iji_1_5000m^2**
fm3ZP	~wind~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m*
fm4	~wind~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m
fm4NB	~wind~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m**
fm4ZP	~wind~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m*
fm5	~wind~log(AREA_MARSH_M2)+pd_1_5000m
fm5NB	~wind~log(AREA_MARSH_M2)+pd_1_5000m**
fm5ZP	~wind~log(AREA_MARSH_M2)+pd_1_5000m*
fm6	~wind~log(AREA_MARSH_M2)+ed_1_1500m
fm6NB	~wind~log(AREA_MARSH_M2)+ed_1_1500m**
fm6ZP	~wind~log(AREA_MARSH_M2)+ed_1_1500m*
fm7	~wind~log(AREA_MARSH_M2)+area_mn_1_400m+area_mn_1_400m^2
fm7NB	~wind~log(AREA_MARSH_M2)+area_mn_1_400m+area_mn_1_400m^2**
fm7ZP	~wind~log(AREA_MARSH_M2)+area_mn_1_400m+area_mn_1_400m^2*
fm8	~wind~log(AREA_MARSH_M2)+pd_1_1500m
fm8NB	~wind~log(AREA_MARSH_M2)+pd_1_1500m**
fm8ZP	~wind~log(AREA_MARSH_M2)+pd_1_1500m*
fm9	~wind~log(AREA_MARSH_M2)+pland_1_5000m
fm9NB	~wind~log(AREA_MARSH_M2)+pland_1_5000m**
fm9ZP	~wind~log(AREA_MARSH_M2)+pland_1_5000m*
null	null

‘*’is negative binomial, ‘**’ is zero-inflated Poisson

Table B.3: List of candidate models and model codes for marsh wrens in 2015 in this study.

Code	Model Parameterization
fm1	~noise+wind+min_af_sunrise~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_spar10_mw50m
fm2	~noise+wind+min_af_sunrise~log(AREA_MARSH_M2)+pland_1_1500m+pland_1_1500m^2
fm3	~noise+wind+min_af_sunrise~log(AREA_MARSH_M2)+area_mn_1_1500m+pland_3_5000m
fm4	~noise+wind+min_af_sunrise~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_urban1nd
fm5	~noise+wind+min_af_sunrise~log(AREA_MARSH_M2)+pland_1_5000m+ed_landcover_15k_water1nd
fm6	~noise+wind+min_af_sunrise~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_junc10_mw50m
fm7	~noise+wind+min_af_sunrise~log(AREA_MARSH_M2)+pland_5_5000m+saltmarsh_junc10_mw50m
fm8	~noise+wind+min_af_sunrise~log(AREA_MARSH_M2)+ed_landcover_15k_nonforn1nd+area_mn_1_400m
fm9	~noise+wind+min_af_sunrise~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+area_mn_1_400m
null	null

Table B.4: List of candidate models and model codes for seaside sparrows in 2015 in this study.

Code	Model Parameterization
fm1	~wind+noise~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr
fm10	~wind+noise~log(AREA_MARSH_M2)+saltmarsh_spar10_mw100m+pland_6_5000m
fm2	~wind+noise~log(AREA_MARSH_M2)+saltmarsh_spar10_mw50m+pland_5_5000m
fm3	~wind+noise~log(AREA_MARSH_M2)+saltmarsh_spar10_mw50m+pland_6_5000m
fm4	~wind+noise~log(AREA_MARSH_M2)+saltmarsh_junc10_mw50m+pland_5_5000m
fm5	~wind+noise~log(AREA_MARSH_M2)+saltmarsh_junc10_mw50m+pland_6_5000m
fm6	~wind+noise~log(AREA_MARSH_M2)+pland_5_5000m+ed_landcover_15k_urban1nd
fm7	~wind+noise~log(AREA_MARSH_M2)+area_mn_1_400m+ed_landcover_15k_urban1nd
fm8	~wind+noise~log(AREA_MARSH_M2)+shape_mn_1_400m+pland_1_5000m+pland_3_5000m
fm9	~wind+noise~log(AREA_MARSH_M2)+saltmarsh_spar10_mw100m+pland_5_5000m
null	null

Table B.5: List of candidate models and model codes for clapper rails in 2016 in this study.

Code	Model Parameterization
fm1	~air_temp+noise ~log(AREA_MARSH_M2)+iji_1_5000m + pland_1_5000m
fm10	~air_temp+noise~log(AREA_MARSH_M2)+lsi_1_400m+area_mn_1_1500m
fm11	~air_temp+noise~log(AREA_MARSH_M2)+MEAN_SAL_PPT+ed_1_400m
fm12	~air_temp+noise~log(AREA_MARSH_M2)+para_mn_1_1500m+ed_2_400m
fm13	~air_temp+noise~log(AREA_MARSH_M2)+pd_1_5000m+I(pd_1_5000m^2)
fm14	~air_temp+noise~log(AREA_MARSH_M2)+pd_1_5000m+ed_landcover_15k_urban1nd
fm15	~air_temp+noise~log(AREA_MARSH_M2)+pd_1_5000m+ed_landcover_15k_fornat1nd
fm2	~air_temp+noise~log(AREA_MARSH_M2)+pd_1_5000m+saltmarsh_spar10_mw50m
fm3	~air_temp+noise~log(AREA_MARSH_M2)+pd_1_5000m+saltmarsh_junc10_mw50m
fm4	~air_temp+noise~log(AREA_MARSH_M2)+shape_mn_1_400m+area_mn_1_1500m
fm5	~air_temp+noise~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m+pland_1_5000m
fm6	~air_temp+noise~log(AREA_MARSH_M2)+pland_1_5000m+ed_1_5000m
fm7	~air_temp+noise~log(AREA_MARSH_M2)+pd_1_1500m+pland_3_5000m
fm8	~air_temp+noise~log(AREA_MARSH_M2)+ed_1_1500m+pland_4_5000m
fm9	~air_temp+noise~log(AREA_MARSH_M2)+ed_1_1500m+pd_4_5000m
null	null

Table B.6: List of candidate models and model codes for KICL in 2016 in this study.

Code	Model Parameterization
fm1	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr
fm10	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_fornat1nd
fm10NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_fornat1nd**
fm10ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_fornat1nd*
fm11	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_4_5000m+saltmarsh_junc10_mw50m
fm11NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_4_5000m+saltmarsh_junc10_mw50m
fm11ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_4_5000m+saltmarsh_junc10_mw50m*
fm12	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_5_5000m

Code	Model Parameterization
fm12NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_5_5000m**
fm12ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_5_5000m*
fm1NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr**
fm1ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr*
fm2	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m
fm2NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m**
fm2ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m*
fm3	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+iji_1_5000m+iji_1_5000m^2
fm3NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+iji_1_5000m+iji_1_5000m^2**
fm3ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m*
fm4	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m
fm4NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m**
fm4ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m*
fm5	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pd_1_5000m
fm5NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pd_1_5000m**
fm5ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pd_1_5000m*
fm6	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+ed_1_1500m
fm6NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+ed_1_1500m**
fm6ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+ed_1_1500m*
fm7	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+area_mn_1_400m+area_mn_1_400m^2
fm7NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+area_mn_1_400m+area_mn_1_400m^2**
fm7ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+area_mn_1_400m+area_mn_1_400m^2*
fm8	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pd_1_1500m
fm8NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pd_1_1500m**
fm8ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pd_1_1500m*
fm9	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_1_5000m
fm9NB	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_1_5000m**
fm9ZP	~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_1_5000m*
null	null

‘*’is negative binomial, ‘**’ is zero-inflated Poisson

Table B.7: List of candidate models and model codes for marsh wrens in 2016 in this study.

Code	Model Parameterization
fm1	~julian_date+air_temp~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_spar10_mw50m
fm2	~julian_date+air_temp~log(AREA_MARSH_M2)+pland_1_1500m+pland_1_1500m^2
fm3	~julian_date+air_temp~log(AREA_MARSH_M2)+area_mn_1_1500m+pland_3_5000m
fm4	~julian_date+air_temp~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_urban1nd
fm5	~julian_date+air_temp~log(AREA_MARSH_M2)+pland_1_5000m+ed_landcover_15k_water1nd
fm6	~julian_date+air_temp~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_junc10_mw50m
fm7	~julian_date+air_temp~log(AREA_MARSH_M2)+pland_5_5000m+saltmarsh_junc10_mw50m
fm8	~julian_date+air_temp~log(AREA_MARSH_M2)+ed_landcover_15k_nonforn1nd+area_mn_1_400m
fm9	~julian_date+air_temp~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+area_mn_1_400m
null	null

Table B.8: List of candidate models and model codes for seaside sparrows in 2016 in this study.

Code	Model Parameterization
fm1	~julian_date+air_temp~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr
fm10	~julian_date+air_temp~log(AREA_MARSH_M2)+saltmarsh_spar10_mw100m+pland_6_5000m
fm2	~julian_date+air_temp~log(AREA_MARSH_M2)+saltmarsh_spar10_mw50m+pland_5_5000m
fm3	~julian_date+air_temp~log(AREA_MARSH_M2)+saltmarsh_spar10_mw50m+pland_6_5000m
fm4	~julian_date+air_temp~log(AREA_MARSH_M2)+saltmarsh_junc10_mw50m+pland_5_5000m
fm5	~julian_date+air_temp~log(AREA_MARSH_M2)+saltmarsh_junc10_mw50m+pland_6_5000m
fm6	~julian_date+air_temp~log(AREA_MARSH_M2)+pland_5_5000m+ed_landcover_15k_urban1nd
fm7	~julian_date+air_temp~log(AREA_MARSH_M2)+area_mn_1_400m+ed_landcover_15k_urban1nd
fm8	~julian_date+air_temp~log(AREA_MARSH_M2)+shape_mn_1_400m+pland_1_5000m+pland_3_5000m
fm9	~julian_date+air_temp~log(AREA_MARSH_M2)+saltmarsh_spar10_mw100m+pland_5_5000m
null	null

Table B.9: List of candidate models and model codes for clapper rails in the pooled data set in this study.

Code	Model Parameterization
fm1	~julian_date+min_af_sunrise+YEAR ~log(AREA_MARSH_M2)+iji_1_5000m + pland_1_5000m
fm10	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+lsi_1_400m+area_mn_1_1500m
fm11	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+MEAN_SAL_PPT+ed_1_400m
fm12	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+para_mn_1_1500m+ed_2_400m
fm13	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+pd_1_5000m+I(pd_1_5000m^2)
fm14	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+pd_1_5000m+ed_landcover_15k_urban1nd
fm15	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+pd_1_5000m+ed_landcover_15k_fornat1nd
fm2	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+pd_1_5000m+saltmarsh_spar10_mw50m
fm3	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+pd_1_5000m+saltmarsh_junc10_mw50m
fm4	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+shape_mn_1_400m+area_mn_1_1500m
fm5	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m+pland_1_5000m
fm6	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+pland_1_5000m+ed_1_5000m
fm7	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+pd_1_1500m+pland_3_5000m
fm8	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+ed_1_1500m+pland_4_5000m
fm9	~julian_date+min_af_sunrise+YEAR~log(AREA_MARSH_M2)+ed_1_1500m+pd_4_5000m
null	null

Table B.10: List of candidate models and model codes for KICL in the pooled data set in this study.

Code	Model Parameterization
fm1	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr
fm10	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_fornat1nd
fm10NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_fornat1nd**
fm10ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_fornat1nd*
fm11	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_4_5000m+saltmarsh_junc10_mw50m
fm11NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_4_5000m+saltmarsh_junc10_mw50m
fm11ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_4_5000m+saltmarsh_junc10_mw50m*
fm12	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_5_5000m

Code	Model Parameterization
fm12NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_5_5000m**
fm12ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_5_5000m*
fm1NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr**
fm1ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr*
fm2	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m
fm2NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m**
fm2ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+saltmarsh_junc10_mw100m*
fm3	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+iji_1_5000m+iji_1_5000m^2
fm3NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+iji_1_5000m+iji_1_5000m^2**
fm3ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m*
fm4	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m
fm4NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m**
fm4ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m*
fm5	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pd_1_5000m
fm5NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pd_1_5000m**
fm5ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pd_1_5000m*
fm6	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+ed_1_1500m
fm6NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+ed_1_1500m**
fm6ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+ed_1_1500m*
fm7	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+area_mn_1_400m+area_mn_1_400m^2
fm7NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+area_mn_1_400m+area_mn_1_400m^2**
fm7ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+area_mn_1_400m+area_mn_1_400m^2*
fm8	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pd_1_1500m
fm8NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pd_1_1500m**
fm8ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pd_1_1500m*
fm9	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_1_5000m
fm9NB	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_1_5000m**
fm9ZP	~julian_date+tidal_stage+YEAR~log(AREA_MARSH_M2)+pland_1_5000m*
null	null

‘*’is negative binomial, ‘**’ is zero-inflated Poisson

Table B.11: List of candidate models and model codes for marsh wrens in the pooled data set in this study.

Code	Model Parameterization
fm1	~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_spar10_mw50m
fm2	~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+pland_1_1500m+pland_1_1500m^2
fm3	~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+area_mn_1_1500m+pland_3_5000m
fm4	~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+area_mn_1_1500m+ed_landcover_15k_urban1nd
fm5	~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+pland_1_5000m+ed_landcover_15k_water1nd
fm6	~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_junc10_mw50m
fm7	~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+pland_5_5000m+saltmarsh_junc10_mw50m
fm8	~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+ed_landcover_15k_nonforn1nd+area_mn_1_400m
fm9	~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+area_mn_1_400m
null	null

Table B.12: List of candidate models and model codes for seaside sparrows in the pooled data set in this study.

Code	Model Parameterization
fm1	~air_temp+YEAR~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr
fm10	~air_temp+YEAR~log(AREA_MARSH_M2)+saltmarsh_spar10_mw100m+pland_6_5000m
fm2	~air_temp+YEAR~log(AREA_MARSH_M2)+saltmarsh_spar10_mw50m+pland_5_5000m
fm3	~air_temp+YEAR~log(AREA_MARSH_M2)+saltmarsh_spar10_mw50m+pland_6_5000m
fm4	~air_temp+YEAR~log(AREA_MARSH_M2)+saltmarsh_junc10_mw50m+pland_5_5000m
fm5	~air_temp+YEAR~log(AREA_MARSH_M2)+saltmarsh_junc10_mw50m+pland_6_5000m
fm6	~air_temp+YEAR~log(AREA_MARSH_M2)+pland_5_5000m+ed_landcover_15k_urban1nd
fm7	~air_temp+YEAR~log(AREA_MARSH_M2)+area_mn_1_400m+ed_landcover_15k_urban1nd
fm8	~air_temp+YEAR~log(AREA_MARSH_M2)+shape_mn_1_400m+pland_1_5000m+pland_3_5000m
fm9	~air_temp+YEAR~log(AREA_MARSH_M2)+saltmarsh_spar10_mw100m+pland_5_5000m
null	null

APPENDIX C: CANDIDATE MODEL AICC RESULTS FOR SECRETIVE MARSH BIRDS

Appendix C contains a summary of the AICc model selection results for all species in all years of this study.

Table C.1: Candidate model AICc results for clapper rail 2015.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm13	7	392.81	0.00	0.98	0.98	-187.60
fm3	7	401.23	8.41	0.01	0.99	-191.81
fm1	7	403.33	10.51	0.01	0.99	-192.86
fm8	7	403.51	10.69	0.00	1.00	-192.95
fm15	7	409.40	16.59	0.00	1.00	-195.89
fm11	7	410.17	17.35	0.00	1.00	-196.28
fm9	7	411.23	18.42	0.00	1.00	-196.81
fm2	7	411.53	18.72	0.00	1.00	-196.96
fm14	7	413.31	20.50	0.00	1.00	-197.85
fm6	7	419.19	26.38	0.00	1.00	-200.79
fm12	7	426.59	33.78	0.00	1.00	-204.49
fm10	7	427.53	34.71	0.00	1.00	-204.96
fm4	7	433.18	40.37	0.00	1.00	-207.78
fm7	7	438.32	45.50	0.00	1.00	-210.35
fm5	7	460.28	67.46	0.00	1.00	-221.33
null	2	506.07	113.26	0.00	1.00	-250.87

Table C.2: Candidate model AICc results for clapper rail 2016.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm8	7	482.20	0.00	1.00	1.00	-232.80
fm11	7	505.95	23.75	0.00	1.00	-244.67
fm3	7	545.18	62.97	0.00	1.00	-264.29
fm1	7	546.37	64.17	0.00	1.00	-264.89
fm9	7	546.89	64.69	0.00	1.00	-265.14
fm13	7	546.98	64.78	0.00	1.00	-265.19
fm12	7	556.30	74.10	0.00	1.00	-269.85

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm6	7	564.51	82.31	0.00	1.00	-273.95
fm2	7	565.91	83.71	0.00	1.00	-274.65
fm15	7	566.45	84.24	0.00	1.00	-274.92
fm14	7	566.82	84.62	0.00	1.00	-275.11
fm7	7	572.04	89.83	0.00	1.00	-277.72
fm5	7	576.49	94.29	0.00	1.00	-279.94
fm4	7	577.45	95.25	0.00	1.00	-280.42
fm10	7	577.99	95.79	0.00	1.00	-280.69
null	2	615.99	133.79	0.00	1.00	-305.80

Table C.3: Candidate model AICc results for the clapper rail in the pooled data set.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm2	8	1002.38	0.00	1.00	1.00	-492.30
fm6	8	1027.40	25.01	0.00	1.00	-504.81
fm8	8	1035.45	33.06	0.00	1.00	-508.83
fm15	8	1036.57	34.18	0.00	1.00	-509.40
fm14	8	1036.73	34.35	0.00	1.00	-509.48
fm3	8	1037.14	34.75	0.00	1.00	-509.68
fm13	8	1037.22	34.84	0.00	1.00	-509.72
fm9	8	1052.66	50.27	0.00	1.00	-517.44
fm7	8	1068.32	65.94	0.00	1.00	-525.27
fm1	8	1074.64	72.25	0.00	1.00	-528.43
fm11	8	1082.96	80.57	0.00	1.00	-532.59
fm10	8	1095.21	92.83	0.00	1.00	-538.72
fm12	8	1096.62	94.24	0.00	1.00	-539.42
fm4	8	1100.12	97.73	0.00	1.00	-541.17
fm5	8	1115.89	113.51	0.00	1.00	-549.06

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
null	2	1121.29	118.91	0.00	1.00	-558.58

Table C.4: Candidate model AICc results for KICL 2015. 'NB'is negative binomial, 'ZP' is zero-inflated Poisson.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm1	6	123.53	0.00	0.34	0.34	-54.45
fm5	5	124.45	0.92	0.21	0.55	-56.32
fm1NB	7	126.52	2.99	0.08	0.62	-54.45
fm1ZP	7	126.53	3.00	0.08	0.70	-54.46
fm3NB	6	126.84	3.30	0.06	0.76	-56.11
fm5ZP	6	127.17	3.63	0.05	0.82	-56.27
fm5NB	6	127.26	3.73	0.05	0.87	-56.32
fm11	6	127.83	4.30	0.04	0.91	-56.60
fm3	5	128.26	4.73	0.03	0.94	-58.22
fm11NB	7	129.63	6.09	0.02	0.96	-56.01
fm4	6	130.07	6.54	0.01	0.97	-57.72
fm11ZP	7	130.82	7.29	0.01	0.98	-56.60
fm3ZP	6	131.07	7.54	0.01	0.99	-58.22
fm6ZP	6	132.13	8.59	0.00	0.99	-58.75
fm4NB	7	133.03	9.50	0.00	0.99	-57.71
fm4ZP	7	133.06	9.53	0.00	1.00	-57.72
fm8	5	135.47	11.94	0.00	1.00	-61.83
fm6	5	135.60	12.06	0.00	1.00	-61.89
fm10ZP	7	136.08	12.55	0.00	1.00	-59.24
fm2ZP	6	137.71	14.18	0.00	1.00	-61.54
fm8NB	6	138.09	14.56	0.00	1.00	-61.73
fm12ZP	6	138.13	14.60	0.00	1.00	-61.75
fm9ZP	6	138.33	14.79	0.00	1.00	-61.85

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm7ZP	6	138.41	14.88	0.00	1.00	-61.89
fm8ZP	6	138.75	15.21	0.00	1.00	-62.06
fm6NB	6	139.07	15.53	0.00	1.00	-62.22
fm10NB	7	139.90	16.36	0.00	1.00	-61.14
fm10	6	141.00	17.46	0.00	1.00	-63.19
fm2	5	143.27	19.74	0.00	1.00	-65.73
fm9	5	144.62	21.09	0.00	1.00	-66.40
fm12	5	145.20	21.66	0.00	1.00	-66.69
fm2NB	6	145.77	22.24	0.00	1.00	-65.57
fm7	5	147.00	23.46	0.00	1.00	-67.59
fm9NB	6	147.43	23.90	0.00	1.00	-66.40
fm12NB	6	148.02	24.49	0.00	1.00	-66.70
fm7NB	6	149.01	25.48	0.00	1.00	-67.19
null	2	234.39	110.85	0.00	1.00	-115.03

Table C.5: Candidate model AICc results for KICL 2016. ‘NB’is negative binomial, ‘ZP’ is zero-inflated Poisson.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm4	10	149.18	0.00	0.68	0.68	-61.84
fm4NB	11	152.13	2.94	0.16	0.83	-61.68
fm4ZP	11	152.15	2.97	0.15	0.99	-61.69
fm5ZP	10	157.89	8.70	0.01	1.00	-66.19
fm5	9	160.80	11.62	0.00	1.00	-69.20
fm5NB	10	163.86	14.68	0.00	1.00	-69.18
fm1	10	164.26	15.08	0.00	1.00	-69.38
fm1NB	11	167.17	17.99	0.00	1.00	-69.20
fm1ZP	11	167.54	18.35	0.00	1.00	-69.38
fm3	9	167.79	18.61	0.00	1.00	-72.70

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm3NB	10	170.44	21.26	0.00	1.00	-72.47
fm3ZP	10	170.92	21.74	0.00	1.00	-72.71
fm8ZP	10	174.81	25.63	0.00	1.00	-74.66
fm8	9	177.52	28.34	0.00	1.00	-77.57
fm8NB	10	180.10	30.92	0.00	1.00	-77.30
fm11NB	11	181.78	32.60	0.00	1.00	-76.51
fm11	10	183.43	34.25	0.00	1.00	-78.96
fm6ZP	10	184.66	35.47	0.00	1.00	-79.58
fm11ZP	11	186.62	37.43	0.00	1.00	-78.92
fm10ZP	11	188.88	39.70	0.00	1.00	-80.05
fm6NB	10	192.12	42.94	0.00	1.00	-83.31
fm9ZP	10	193.66	44.48	0.00	1.00	-84.08
fm2ZP	10	193.73	44.55	0.00	1.00	-84.12
fm7ZP	10	193.76	44.58	0.00	1.00	-84.13
fm12ZP	10	193.81	44.63	0.00	1.00	-84.16
fm12NB	10	193.97	44.79	0.00	1.00	-84.24
fm10NB	11	199.75	50.57	0.00	1.00	-85.49
fm12	9	204.53	55.34	0.00	1.00	-91.07
fm6	9	205.19	56.00	0.00	1.00	-91.40
fm10	10	209.19	60.01	0.00	1.00	-91.84
fm2NB	10	209.31	60.13	0.00	1.00	-91.91
fm9NB	10	211.32	62.14	0.00	1.00	-92.91
fm7NB	10	211.62	62.44	0.00	1.00	-93.06
fm2	9	231.72	82.54	0.00	1.00	-104.67
fm9	9	250.44	101.26	0.00	1.00	-114.02
fm7	9	251.84	102.66	0.00	1.00	-114.72
null	2	327.67	178.49	0.00	1.00	-161.70

Table C.6: Candidate model AICc results for the KICL in the pooled data set. ‘NB’is negative binomial, ‘ZP’ is zero-inflated Poisson.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm8ZP	10	348.50	0.00	0.38	0.38	-162.86
fm6ZP	10	348.88	0.38	0.31	0.69	-163.05
fm5ZP	10	350.65	2.15	0.13	0.81	-163.93
fm4ZP	11	352.24	3.74	0.06	0.87	-163.43
fm10ZP	11	352.32	3.82	0.06	0.93	-163.47
fm12ZP	10	354.86	6.36	0.02	0.94	-166.04
fm1ZP	11	355.15	6.65	0.01	0.96	-164.88
fm9ZP	10	355.30	6.80	0.01	0.97	-166.26
fm2ZP	10	356.06	7.56	0.01	0.98	-166.64
fm11ZP	11	356.20	7.71	0.01	0.99	-165.41
fm3ZP	10	356.44	7.94	0.01	0.99	-166.83
fm7ZP	10	356.53	8.03	0.01	1.00	-166.87
fm5NB	10	367.75	19.26	0.00	1.00	-172.49
fm6NB	10	374.04	25.55	0.00	1.00	-175.63
fm3NB	10	375.11	26.62	0.00	1.00	-176.16
fm8NB	10	380.58	32.09	0.00	1.00	-178.90
fm1NB	11	381.34	32.85	0.00	1.00	-177.98
fm9NB	10	382.06	33.57	0.00	1.00	-179.64
fm7NB	10	382.46	33.96	0.00	1.00	-179.84
fm2NB	10	382.50	34.00	0.00	1.00	-179.86
fm12NB	10	382.71	34.22	0.00	1.00	-179.96
fm4NB	11	383.47	34.97	0.00	1.00	-179.04
fm11NB	11	383.50	35.01	0.00	1.00	-179.06
fm10NB	11	384.63	36.13	0.00	1.00	-179.62
fm5	9	469.52	121.02	0.00	1.00	-224.64
fm3	9	479.57	131.07	0.00	1.00	-229.66
fm1	10	488.20	139.70	0.00	1.00	-232.71

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm6	9	493.38	144.88	0.00	1.00	-236.56
fm4	10	494.41	145.91	0.00	1.00	-235.81
fm11	10	495.25	146.76	0.00	1.00	-236.23
fm8	9	507.47	158.98	0.00	1.00	-243.61
fm12	9	517.06	168.56	0.00	1.00	-248.40
fm2	9	519.70	171.20	0.00	1.00	-249.72
fm9	9	524.20	175.71	0.00	1.00	-251.98
fm10	10	526.05	177.56	0.00	1.00	-251.63
fm7	9	527.69	179.19	0.00	1.00	-253.72
null	2	563.97	215.47	0.00	1.00	-279.91

Table C.7: Candidate model AICc results for marsh wren 2015.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm9	8	342.34	0.00	0.47	0.47	-160.77
fm1	8	343.35	1.01	0.29	0.76	-161.28
fm6	8	344.05	1.72	0.20	0.96	-161.63
fm8	8	349.21	6.87	0.02	0.98	-164.20
fm4	8	350.56	8.23	0.01	0.98	-164.88
fm5	8	350.65	8.31	0.01	0.99	-164.92
fm2	7	351.19	8.85	0.01	1.00	-166.79
fm7	8	353.48	11.15	0.00	1.00	-166.34
fm3	8	354.64	12.30	0.00	1.00	-166.92
null	2	377.67	35.33	0.00	1.00	-186.67

Table C.8: Candidate model AICc results for marsh wren 2016.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm1	7	283.53	0.00	0.68	0.68	-133.46
fm7	7	286.92	3.40	0.12	0.81	-135.16
fm8	7	287.95	4.43	0.07	0.88	-135.67
fm6	7	288.15	4.62	0.07	0.95	-135.77
fm9	7	290.06	6.54	0.03	0.98	-136.73
fm2	6	291.38	7.85	0.01	0.99	-138.73
fm3	7	292.66	9.13	0.01	1.00	-138.03
fm4	7	294.53	11.00	0.00	1.00	-138.96
fm5	7	296.68	13.16	0.00	1.00	-140.04
null	2	330.27	46.75	0.00	1.00	-163.01

Table C.9: Candidate model AICc results for marsh wren in the pooled data set.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm6	8	700.18	0.00	0.37	0.37	-341.20
fm9	8	701.17	0.99	0.22	0.59	-341.70
fm1	8	701.31	1.14	0.21	0.80	-341.77
fm7	8	702.33	2.15	0.13	0.93	-342.27
fm3	8	704.76	4.58	0.04	0.97	-343.49
fm8	8	705.51	5.33	0.03	0.99	-343.87
fm2	7	709.32	9.15	0.00	1.00	-346.98
fm4	8	710.21	10.03	0.00	1.00	-346.21
fm5	8	711.42	11.24	0.00	1.00	-346.82
null	2	718.74	18.56	0.00	1.00	-357.30

Table C.10: Candidate model AICc results for seaside sparrow 2015.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm6	7	229.97	0.00	0.35	0.35	-106.18
fm1	7	230.81	0.84	0.23	0.58	-106.60
fm4	7	231.15	1.18	0.19	0.77	-106.77
fm2	7	232.30	2.33	0.11	0.88	-107.34
fm9	7	232.45	2.48	0.10	0.98	-107.42
fm5	7	235.83	5.86	0.02	1.00	-109.11
fm3	7	240.83	10.86	0.00	1.00	-111.61
fm10	7	240.91	10.94	0.00	1.00	-111.65
fm7	7	248.59	18.62	0.00	1.00	-115.49
null	2	252.95	22.99	0.00	1.00	-124.31
fm8	8	253.50	23.53	0.00	1.00	-116.35

Table C.11: Candidate model AICc results for seaside sparrow 2016

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm6	7	95.12	0.00	0.87	0.87	-39.26
fm4	7	99.73	4.61	0.09	0.96	-41.56
fm2	7	102.76	7.64	0.02	0.98	-43.08
fm9	7	102.84	7.72	0.02	1.00	-43.12
fm10	7	106.72	11.60	0.00	1.00	-45.06
fm3	7	109.83	14.71	0.00	1.00	-46.61
fm5	7	110.49	15.37	0.00	1.00	-46.94
fm1	7	113.04	17.92	0.00	1.00	-48.22
fm7	7	118.20	23.08	0.00	1.00	-50.80
fm8	8	119.17	24.05	0.00	1.00	-49.87
null	2	126.44	31.32	0.00	1.00	-61.10

Table C.12: Candidate model AICc results for seaside sparrow in the pooled data set.

Model	K	AICc	Δ AICc	AICc Weight	Cum. Weight	LL
fm10	7	385.81	0.00	0.74	0.74	-185.22
fm9	7	389.86	4.05	0.10	0.84	-187.25
fm3	7	391.11	5.31	0.05	0.89	-187.87
fm2	7	391.40	5.59	0.05	0.94	-188.02
fm6	7	392.26	6.45	0.03	0.97	-188.45
fm4	7	393.19	7.38	0.02	0.99	-188.91
fm5	7	394.21	8.41	0.01	1.00	-189.42
fm1	7	397.66	11.85	0.00	1.00	-191.15
fm7	7	401.30	15.50	0.00	1.00	-192.97
fm8	8	403.39	17.58	0.00	1.00	-192.81
null	2	404.42	18.62	0.00	1.00	-200.14

APPENDIX D: GOODNESS-OF-FIT PARAMETRIC BOOTSTRAPPING RESULTS FOR MODELS OF ABUNDANCE

Appendix D Contains the metrics of model fit for abundance models used in this study.

Table D.1: Goodness-of-fit parameteric bootstrapping (N=1,000 simulations) results of top models for clapper rail in this study.

Model Parameterization pooled data:
~p. julian_date+noise~N. log(AREA_MARSH_M2)+pd_1_5000m+I(pd_1_5000m^2)

Goodness-of-fit Statistic	Dispersion Factor	t0	Mean (t0 - t_B)	StdDev (t0 - t_B)	Pr (t_B > t0)
Sum of squared errors	---	1436.34	593.98	113.95	0.00
Chisq	---	446.81	221.96	25.56	0.00
freemanTukey	---	194.88	116.91	9.58	0.00
rmse	---	2.47	-0.04	0.04	0.83
c-hat	1.99	---	---	---	---

Model Parameterization 2015:
~p. julian_date+noise~N. log(AREA_MARSH_M2)+pd_1_5000m+I(pd_1_5000m^2)

Goodness-of-fit Statistic	Dispersion Factor	t0	Mean (t0 - t_B)	StdDev (t0 - t_B)	Pr (t_B > t0)
SSE	---	379.42	22.59	76.18	0.35
Chisq	---	117.76	15.30	16.32	0.18
freemanTukey	---	42.61	5.54	5.55	0.16
rmse	---	1.85	-0.09	0.09	0.85
c-hat	1.15	---	---	---	---

Model Parameterization 2016:
~p. air_temp+noise~N. log(AREA_MARSH_M2)+ed_1_1500m+pland_4_5000m

Goodness-of-fit Statistic	Dispersion Factor	t0	Mean (t0 - t_B)	StdDev (t0 - t_B)	Pr (t_B > t0)
Sum of squared errors	---	542.88	89.31	74.71	0.12
Chisq	---	138.24	21.66	15.25	0.08
freemanTukey	---	52.55	14.70	5.23	0.01
rmse	---	2.09	-0.06	0.06	0.86
c-hat	1.19	---	---	---	---

t0 = Original statistic computed from data
t_B = Vector of bootstrap samples

Table D.2: Goodness-of-fit parametric bootstrapping (N=1,000 simulations) results of top models for KICL in this study.

Model Parameterization pooled data:
~p. julian_date+tidal_stage+YEAR~N. log(AREA_MARSH_M2)+pd_1_1500m* '*'is negative binomial, '**' is zero-inflated Poisson

Goodness-of-fit Statistic	Dispersion Factor	t0	Mean (t0 - t_B)	StdDev (t0 - t_B)	Pr (t_B > t0)
Sum of squared errors	---	739.76	-243.50	257.31	0.81
Chisq	---	819.60	-24.52	96.18	0.58
freemanTukey	---	230.03	6.63	29.79	0.44
rmse	---	1.77	-0.03	0.09	0.55
c-hat	0.97	---	---	---	---

Model Parameterization pooled data:
~p. julian_date+tidal_stage+YEAR~N. log(AREA_MARSH_M2)+ed_1_1500m*'*'is negative binomial, '**' is zero-inflated Poisson

Goodness-of-fit Statistic	Dispersion Factor	t0	Mean (t0 - t_B)	StdDev (t0 - t_B)	Pr (t_B > t0)
Sum of squared errors	---	1192.88	-1240.00	804.84	0.95
Chisq	---	914.09	-208.00	152.17	0.94
freemanTukey	---	320.12	7.78	39.36	0.45
rmse	---	2.25	-0.04	0.25	0.52
c-hat	0.81	---	---	---	---

Model Parameterization 2015:
~p. wind~N. log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr

Goodness-of-fit Statistic	Dispersion Factor	t0	Mean (t0 - t_B)	StdDev (t0 - t_B)	Pr (t_B > t0)
Sum of squared errors	---	56.70	-7.06	27.32	0.52
Chisq	---	236.31	142.41	54.04	0.02
freemanTukey	---	11.16	-2.42	4.71	0.68
rmse	---	0.72	-0.15	0.14	0.10
c-hat	2.52	---	---	---	---

Model Parameterization 2015:
~p. wind~N. log(AREA_MARSH_M2)+pd_1_5000m

Goodness-of-fit Statistic	Dispersion Factor	t0	Mean (t0 - t_B)	StdDev (t0 - t_B)	Pr (t_B > t0)
Sum of squared errors	---	816.38	468.08	74.19	0.00
Chisq	---	250.64	150.11	17.55	0.00
freemanTukey	---	91.42	55.82	6.88	0.00
rmse	---	4.01	-0.03	0.28	0.52
c-hat	2.49	---	---	---	---

Model Parameterization 2016:
~julian_date+tidal_stage+noise~log(AREA_MARSH_M2)+pland_4_5000m+pland_1_5000m

Goodness-of-fit Statistic	Dispersion Factor	t0	Mean (t0 - t_B)	StdDev (t0 - t_B)	Pr (t_B > t0)
Sum of squared errors	---	90.42	20.64	22.23	0.17
Chisq	---	32.35	4.60	12.16	0.22
freemanTukey	---	14.85	4.96	2.98	0.06
rmse	---	0.85	-0.10	0.06	0.02
c-hat	1.17	---	---	---	---

t0 = Original statistic computed from data

t_B = Vector of bootstrap samples

Table D.3: Goodness-of-fit parameteric bootstrapping (N=1,000 simulations) results of top models for marsh wren in this study.

Model Parameterization pooled data:
~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_junc10_mw50m

Goodness-of-fit Statistic	Dispersion Factor	t0	mean(t0 - t_B)	StdDev(t0 - t_B)	Pr(t_B > t0)
Sum of squared errors	---	417.59	154.26	33.25	0.00
Chisq	---	362.04	136.48	21.57	0.00
freemanTukey	---	139.96	40.70	7.36	0.00
rmse	---	1.33	-0.02	0.01	1.00
c-hat	1.61		---	---	---

Model Parameterization pooled data:
~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+area_mn_1_400m

Goodness-of-fit Statistic	**Dispersion Factor**	**t0**	**mean(t0 - t_B)**	**StdDev(t0 - t_B)**	**Pr(t_B > t0)**
Sum of squared errors	---	419.97	155.69	34.67	0.00
Chisq	---	363.70	137.23	22.58	0.00
freemanTukey	---	140.42	40.74	7.29	0.00
rmse	---	1.34	-0.02	0.01	0.97
c-hat	1.61	---	---	---	---

Model Parameterization pooled data:
~julian_date+air_temp+YEAR~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_spar10_mw50m

Goodness-of-fit Statistic	**Dispersion Factor**	**t0**	**mean(t0 - t_B)**	**StdDev(t0 - t_B)**	**Pr(t_B > t0)**
Sum of squared errors	---	105.60	6.49	19.88	0.33
Chisq	---	130.30	12.84	18.48	0.20
freemanTukey	---	44.80	1.64	4.72	0.35
rmse	---	1.60	-0.02	0.05	0.66
c-hat	1.11	---	---	---	---

Model Parameterization 2015:
~noise+wind+noise~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+area_mn_1_400m

Goodness-of-fit Statistic	**Dispersion Factor**	**t0**	**mean(t0 - t_B)**	**StdDev(t0 - t_B)**	**Pr(t_B > t0)**
Sum of squared errors	---	173.09	18.04	29.35	0.26
Chisq	---	119.52	16.15	15.20	0.13
freemanTukey	---	50.97	8.78	5.31	0.05
rmse	---	1.25	-0.05	0.03	1.00
c-hat	1.16		---	---	---

Model Parameterization 2015:
~noise+wind+noise~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_spar10_mw50m

Goodness-of-fit Statistic	Dispersion Factor	t0	mean(t0 - t_B)	StdDev(t0 - t_B)	Pr(t_B > t0)
Sum of squared errors	---	177.44	24.77	27.83	0.18
Chisq	---	116.38	13.96	14.83	0.17
freemanTukey	---	52.05	9.90	5.19	0.04
rmse	---	1.26	-0.05	0.03	1.00
c-hat	1.14	---	---	---	---

Model Parameterization 2015: ~noise+wind+noise~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_junc10_mw50m

Goodness-of-fit Statistic	Dispersion Factor	t0	mean(t0 - t_B)	StdDev(t0 - t_B)	Pr(t_B > t0)
Sum of squared errors	---	176.97	24.50	28.72	0.19
Chisq	---	120.78	17.29	15.18	0.13
freemanTukey	---	52.01	9.60	5.28	0.04
rmse	---	1.26	-0.05	0.03	1.00
c-hat	1.17	---	---	---	---

Model Parameterization 2016:
~julian_date+air_temp~log(AREA_MARSH_M2)+ed_landcover_15k_fornat1nd+saltmarsh_spar10_mw50m

Goodness-of-fit Statistic	Dispersion Factor	t0	mean(t0 - t_B)	StdDev(t0 - t_B)	Pr(t_B > t0)
Sum of squared errors	---	105.57	5.47	20.71	0.36
Chisq	---	130.27	12.57	17.24	0.21
freemanTukey	---	44.85	1.43	4.70	0.38
rmse	---	0.92	-0.04	0.03	0.05
c-hat	1.11	---	---	---	---

t0 = Original statistic computed from data

t_B = Vector of bootstrap samples

Table D.4: Goodness-of-fit parameteric bootstrapping (N=1,000 simulations) results of top models for seaside sparrow in this study.

Model Parameterization pooled data:
~p. air_temp+YEAR~N. log(Fs_marsh_200)+saltmarsh_spar10_mw100m+pland_6_5000m

Goodness-of-fit Statistic	Dispersion Factor	t0	mean(t0 - t_B)	StdDev(t0 - t_B)	Pr(t_B > t0)
Sum of squared errors	---	166.93	65.53	19.07	0.00
Chisq	---	393.39	167.53	27.68	0.00
freemanTukey	---	91.46	19.36	6.80	0.00
rmse	---	0.84	-0.02	0.02	0.20
c-hat	1.74	---	---	---	---

Model Parameterization 2015:
~wind+noise~log(AREA_MARSH_M2)+pland_5_5000m+ed_landcover_15k_urban1nd

Goodness-of-fit Statistic	Dispersion Factor	t0	mean(t0 - t_B)	StdDev(t0 - t_B)	Pr(t_B > t0)
Sum of squared errors	---	193.75	40.55	27.24	0.08
Chisq	---	125.59	22.89	15.19	0.07
freemanTukey	---	55.35	12.86	5.25	0.01
rmse	---	1.32	-0.04	0.03	1.00
c-hat	1.22	---	---	---	---

Model Parameterization 2015:
~wind+noise~log(AREA_MARSH_M2)+MEAN_SAL_PPT+secn_dem_mtr

Goodness-of-fit Statistic	Dispersion Factor	t0	mean(t0 - t_B)	StdDev(t0 - t_B)	Pr(t_B > t0)
Sum of squared errors	---	186.60	30.64	28.56	0.14
Chisq	---	120.50	15.98	27.45	0.13
freemanTukey	---	54.20	11.97	5.15	0.01
rmse	---	1.30	-0.04	0.02	0.99
c-hat	1.15	---	---	---	---

Model Parameterization 2015:
~wind+noise~log(AREA_MARSH_M2)+saltmarsh_junc10_mw50m+pland_5_5000m

Goodness-of-fit Statistic	Dispersion Factor	t0	mean(t0 - t_B)	StdDev(t0 - t_B)	Pr(t_B > t0)
Sum of squared errors	---	203.31	49.74	28.45	0.05
Chisq	---	128.95	25.63	15.24	0.06
freemanTukey	---	57.69	14.77	5.45	0.01
rmse	---	1.35	-0.04	0.02	1.00
c-hat	1.25	---	---	---	---

Model Parameterization 2016:
~p. wind+noise~N. log(AREA_MARSH_M2)+pland_5_5000m+ed_landcover_15k_urban1nd

Goodness-of-fit Statistic	Dispersion Factor	t0	mean(t0 - t_B)	StdDev(t0 - t_B)	Pr(t_B > t0)
Sum of squared errors	---	33.98	17.17	6.51	0.02
Chisq	---	116.89	28.23	117.72	0.13
freemanTukey	---	17.21	4.36	3.26	0.10
rmse	---	0.52	-0.03	0.03	0.14
c-hat	1.32	---	---	---	---

t0 = Original statistic computed from data

t_B = Vector of bootstrap samples

APPENDIX E: AVIAN SURVEY SUMMARY FIGURES AND SPECIES PREDICTION MAPS

Appendix E contains summary figures for surveys conducted in 2015-2016, and species prediction maps based on top models.

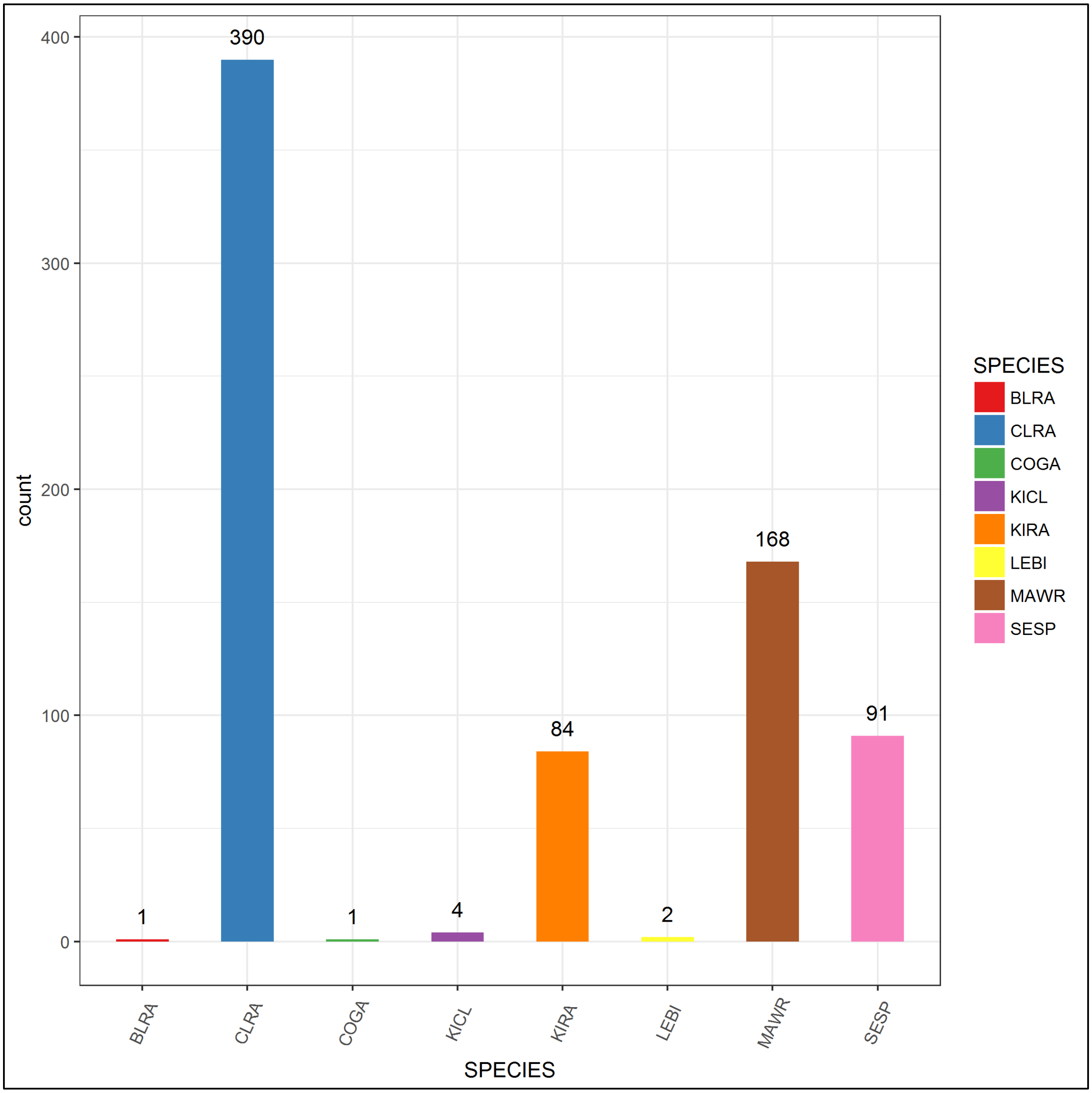

Figure E.1: Histogram of species detections in 2015.

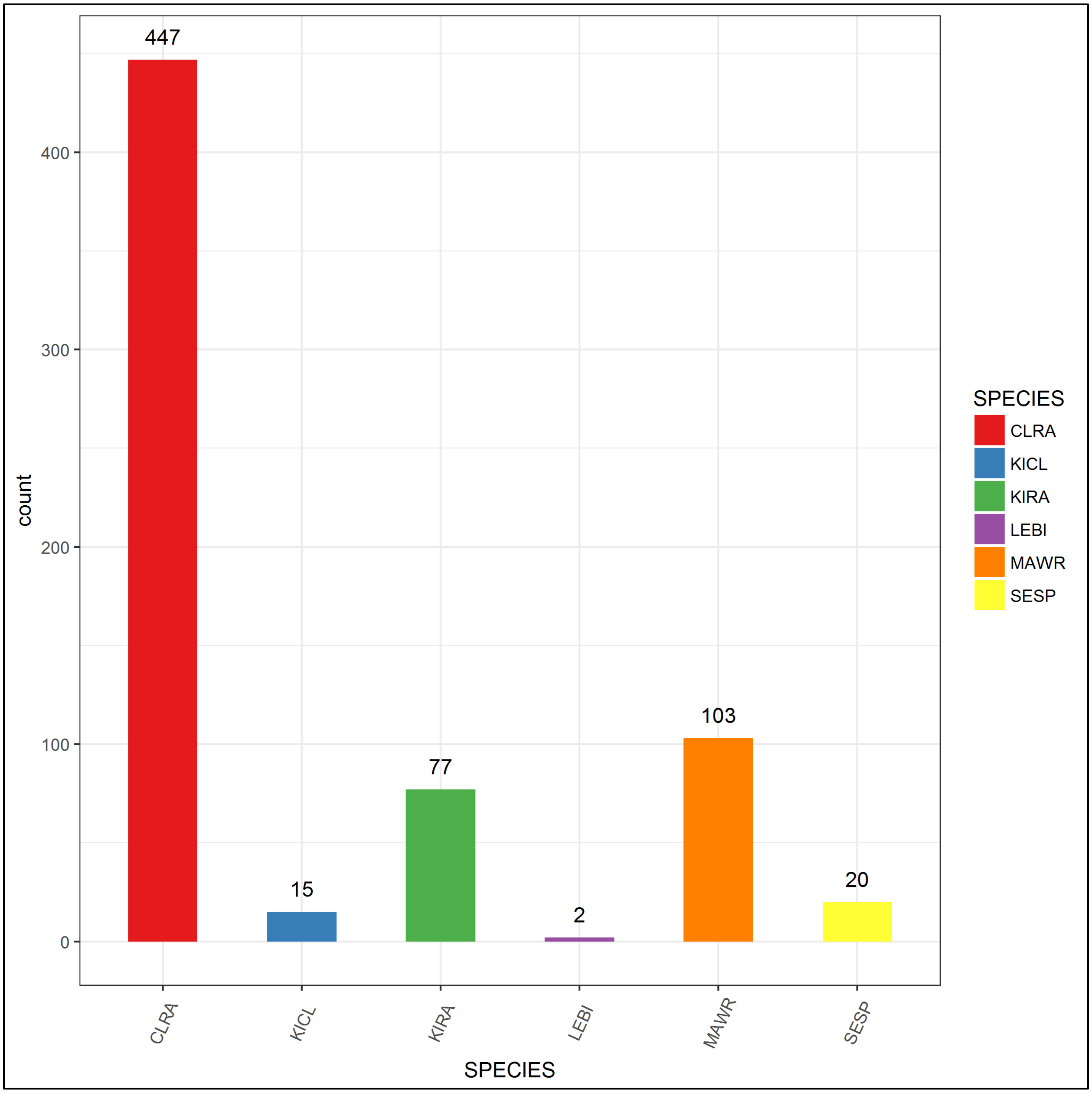

Figure E.2: Histogram of species detections in 2016.

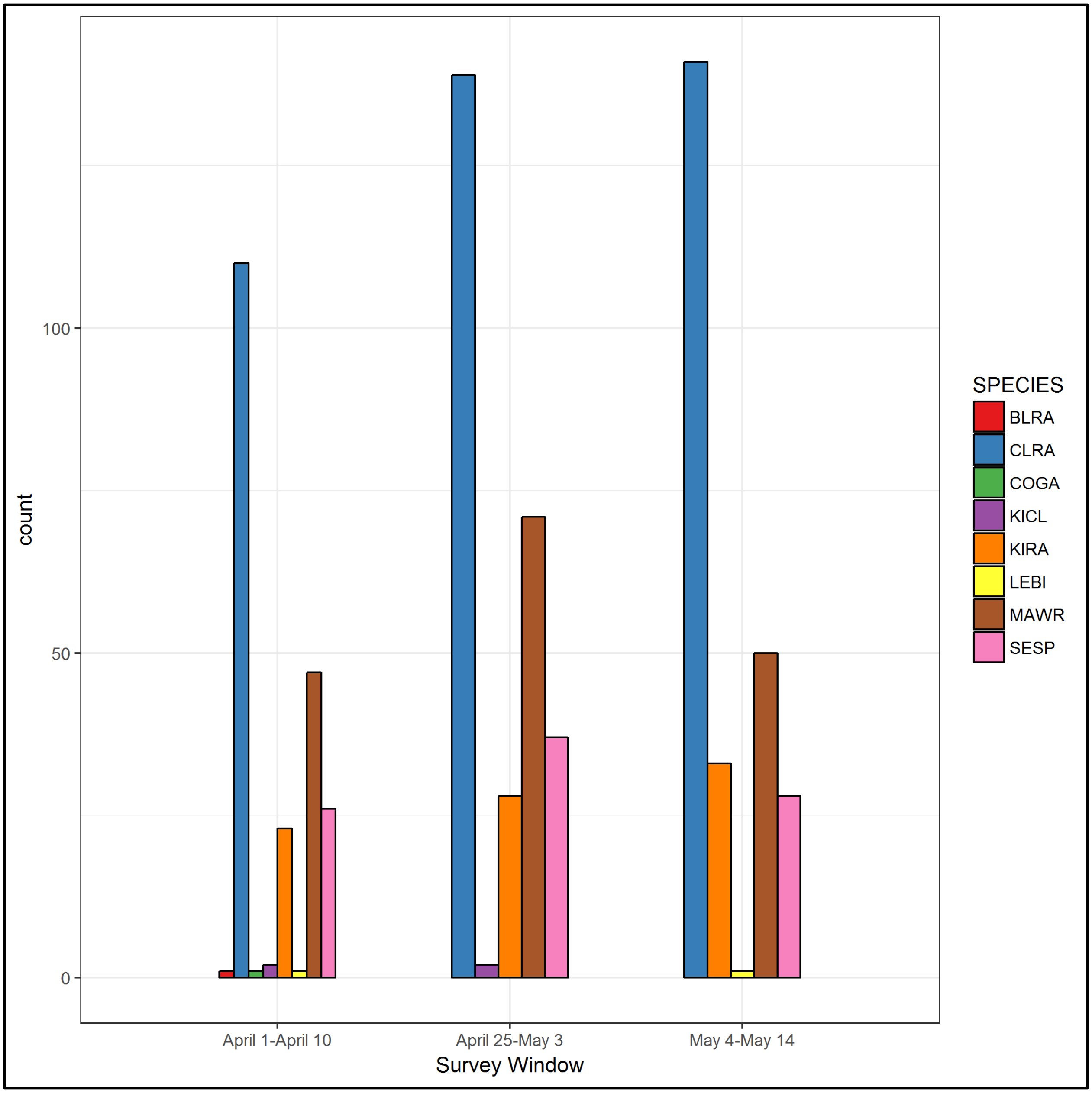

Figure E.3: Histogram of species detections by survey window in 2015.

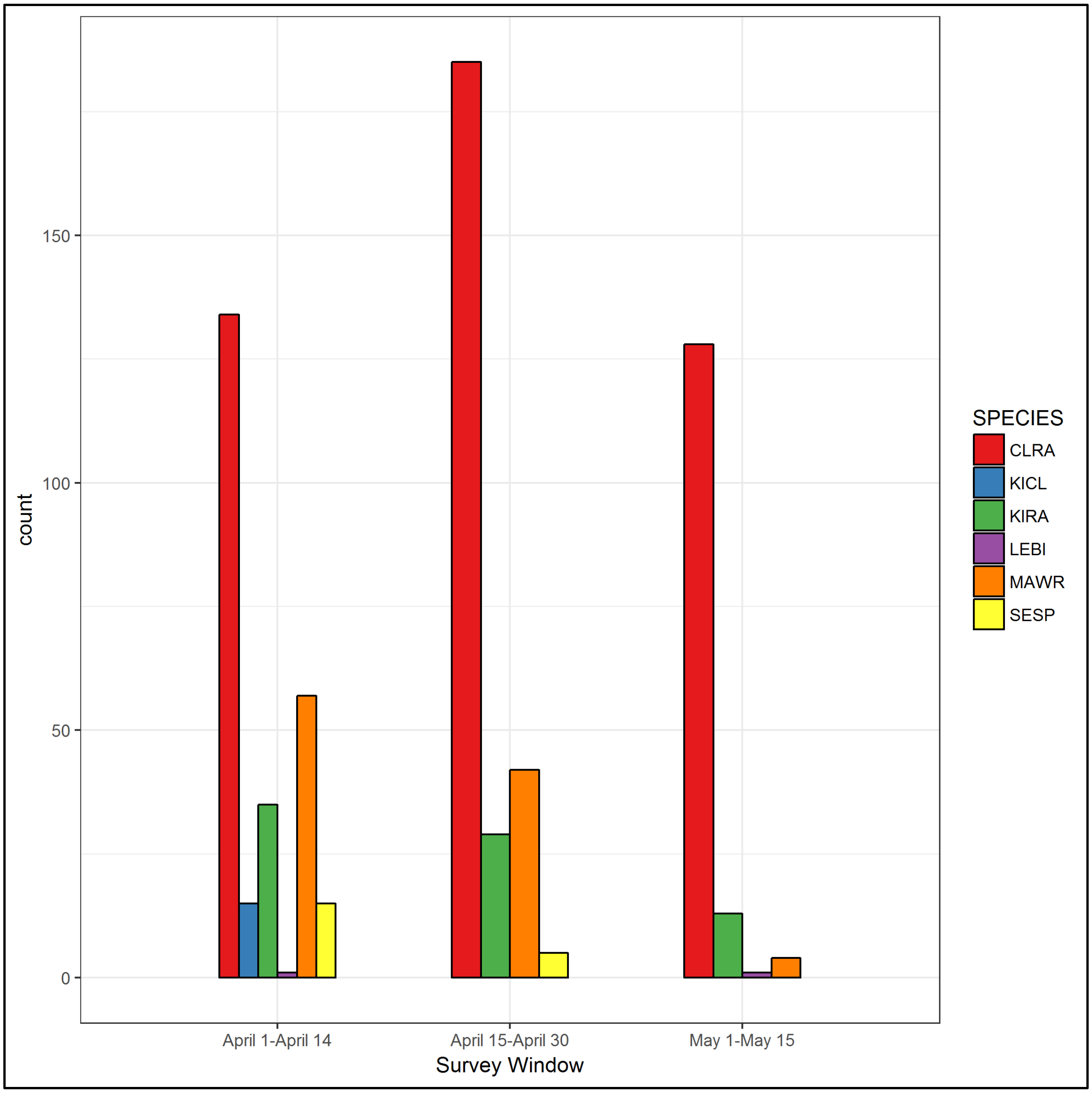

Figure E.4: Histogram of species detections by survey window in 2016.

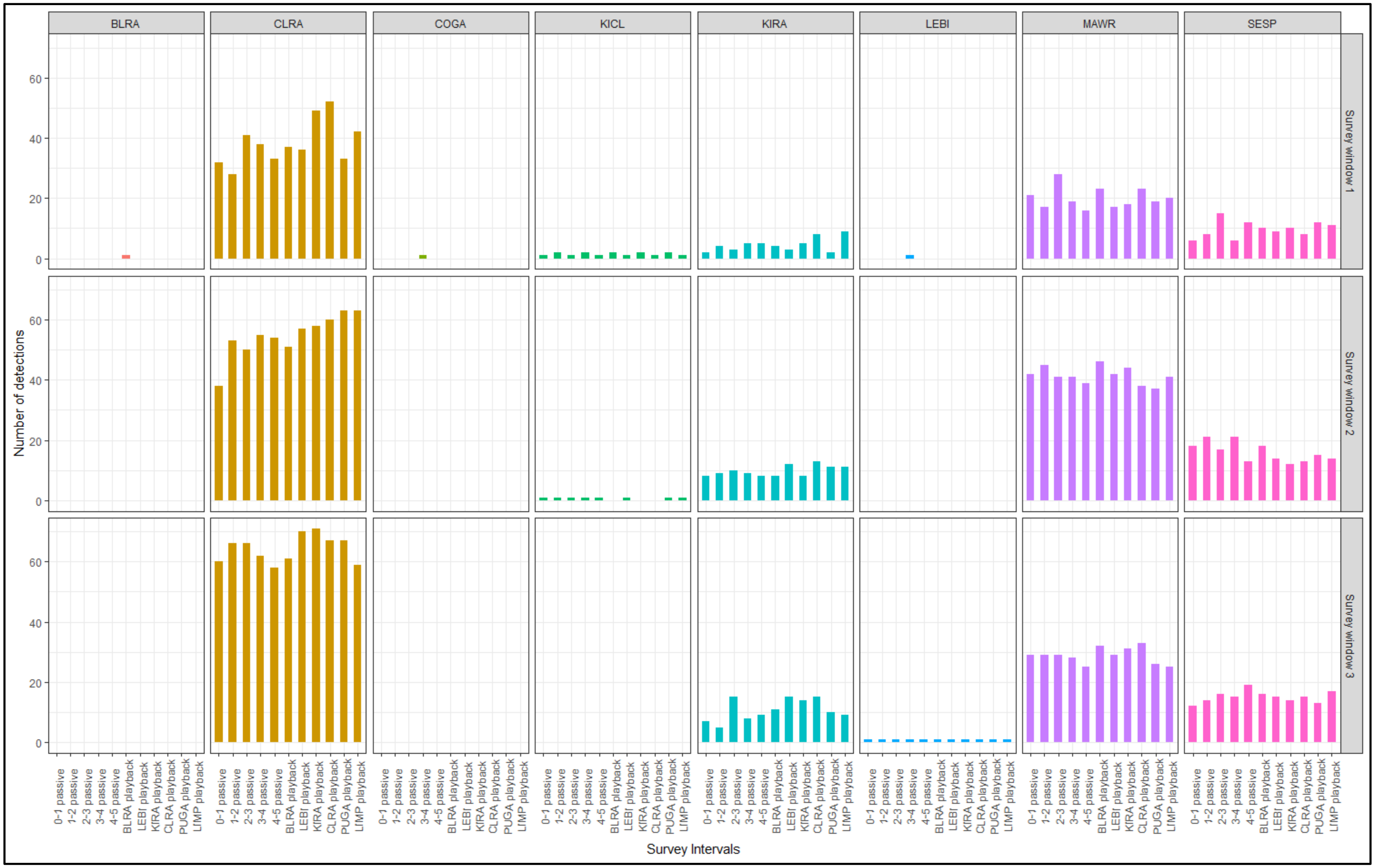

Figure E.5: Histogram of species detections by survey window by species in 2015.

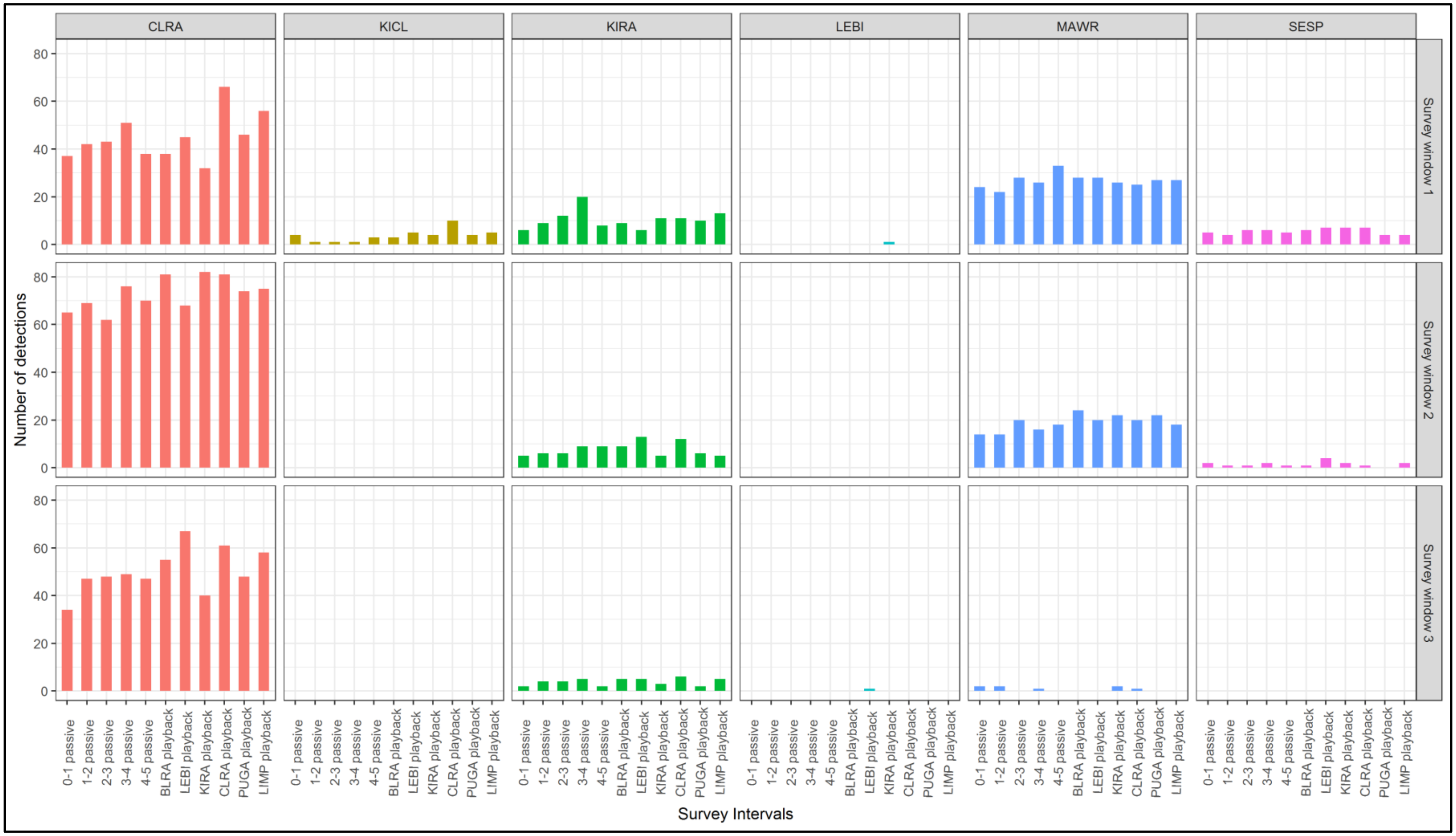

Figure E.6: Histogram of species detections by survey window by species in 2016.

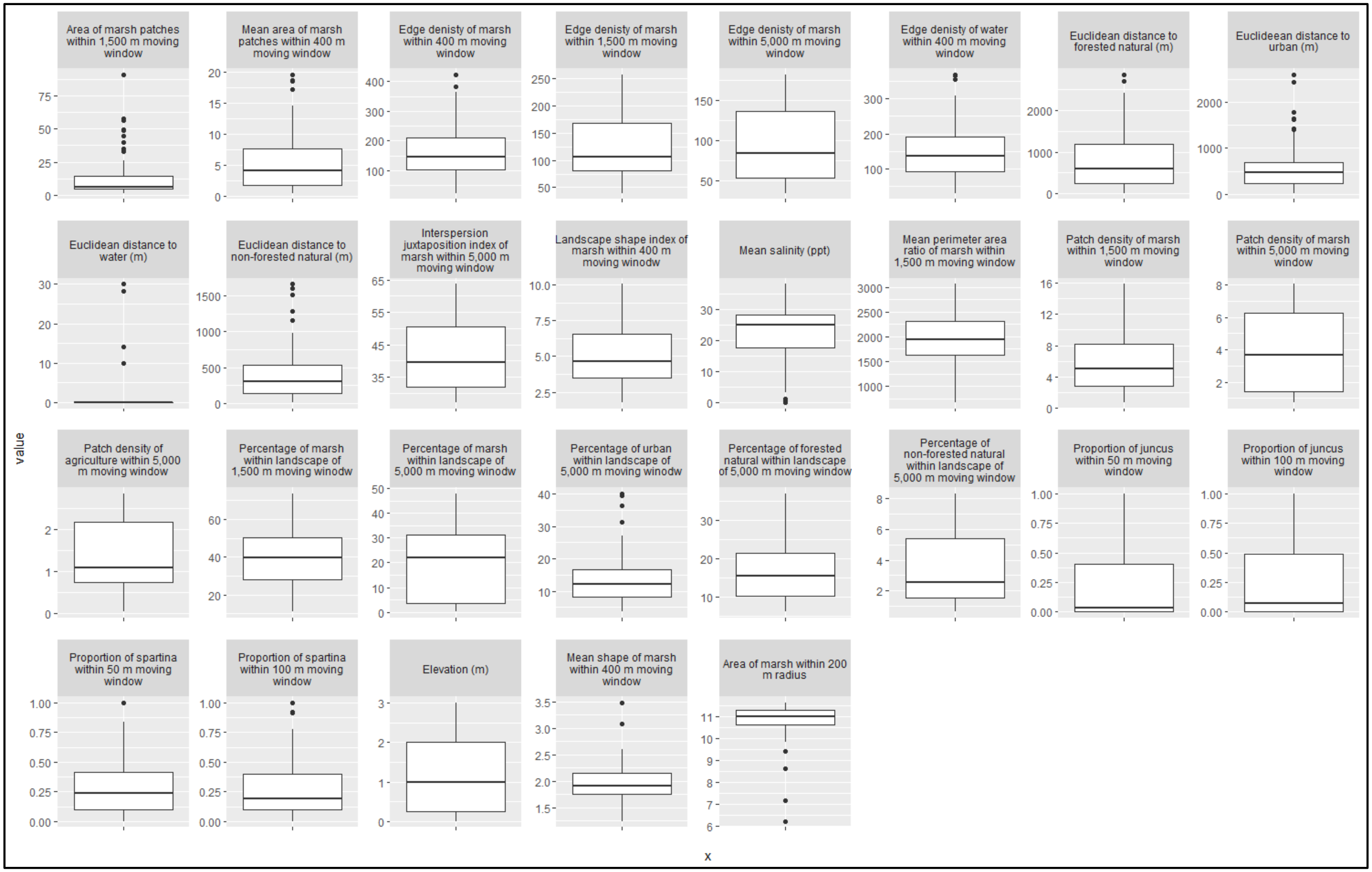

Figure E.7: Box plots of covariates used in abundance models in the 2015-2016 analyses.

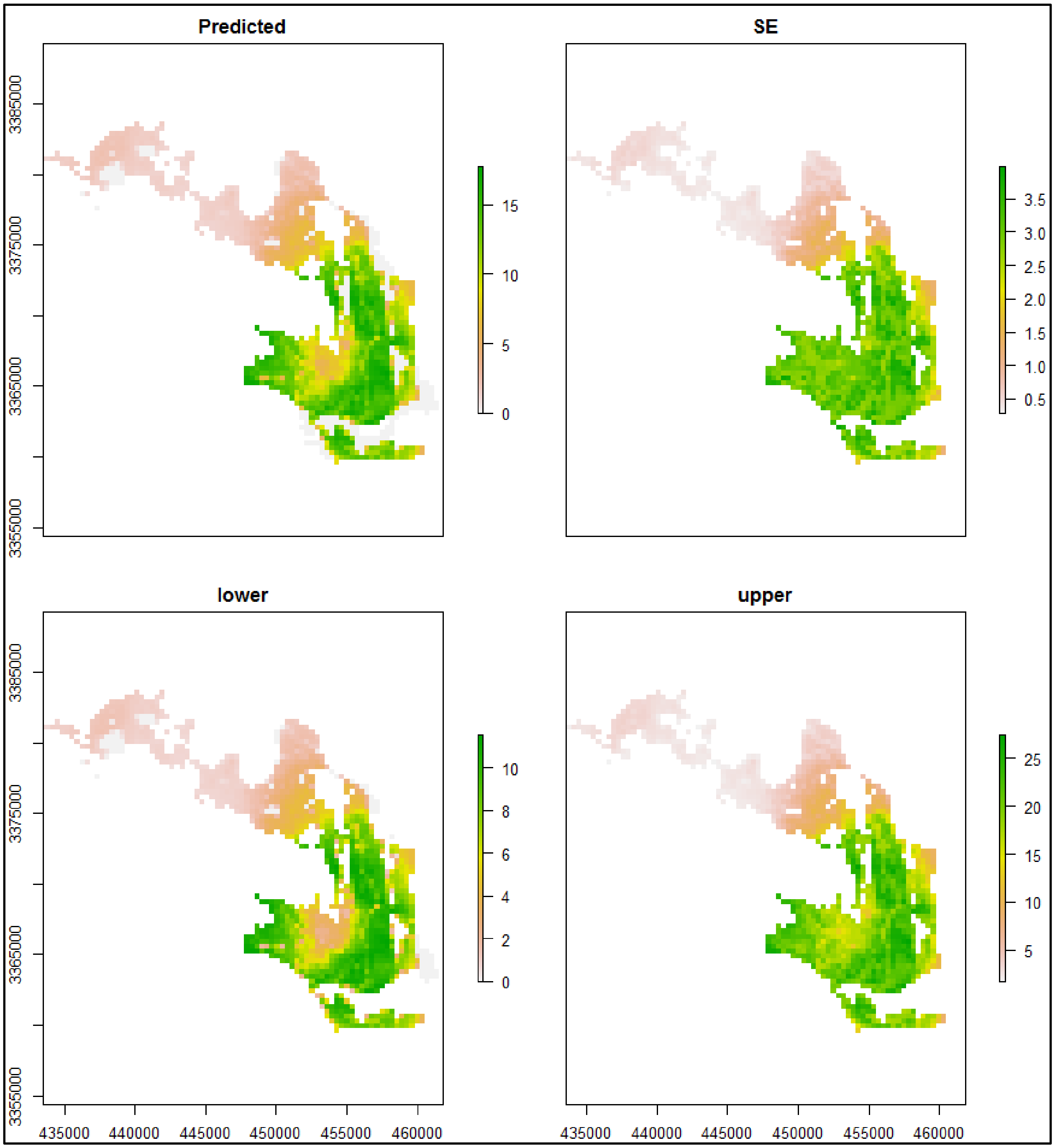

Figure E.8: Predicted clapper rail abundance in 2015 under model fm13.

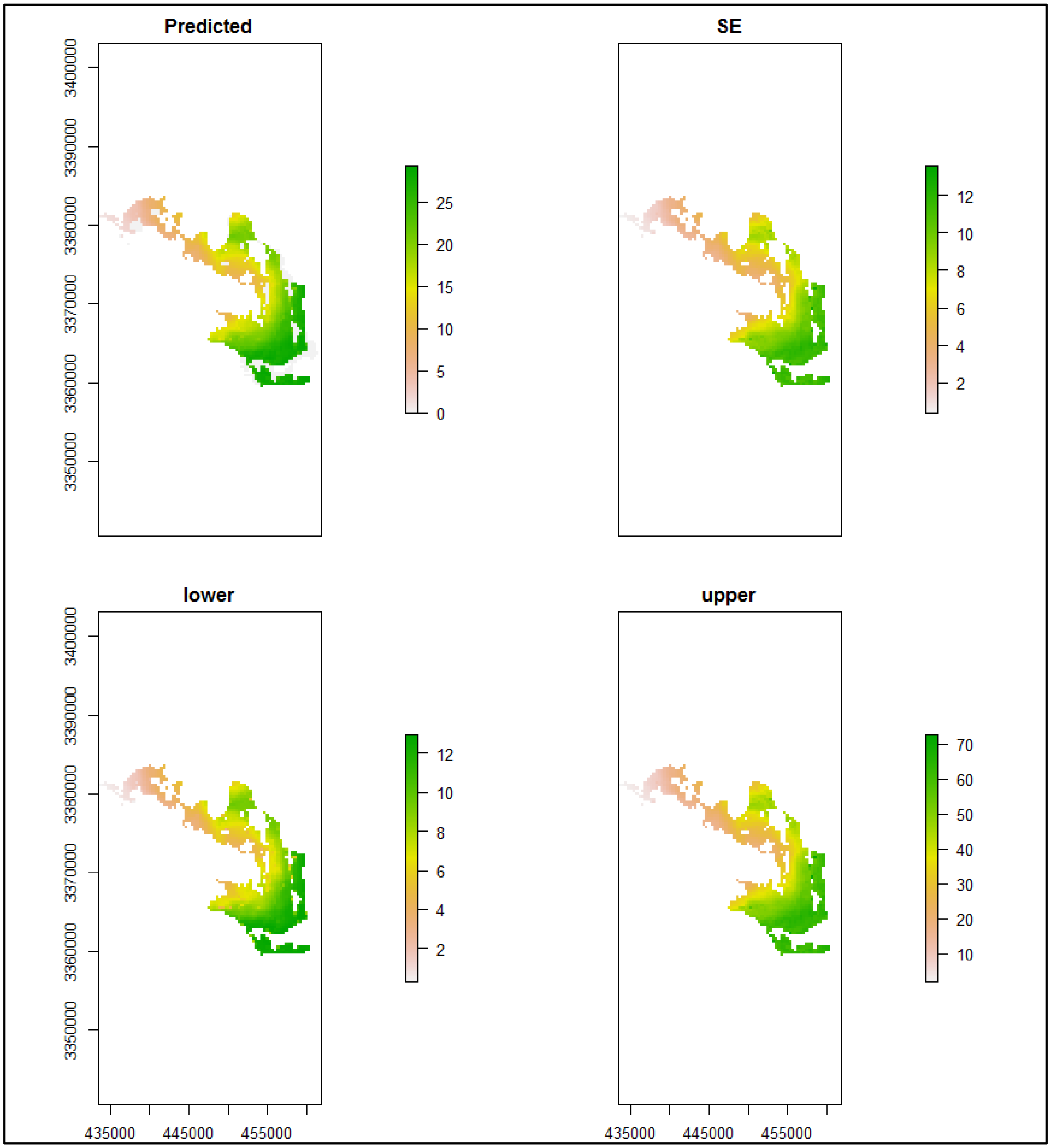

Figure E.9: Predicted clapper rail abundance in 2016 under model fm8.

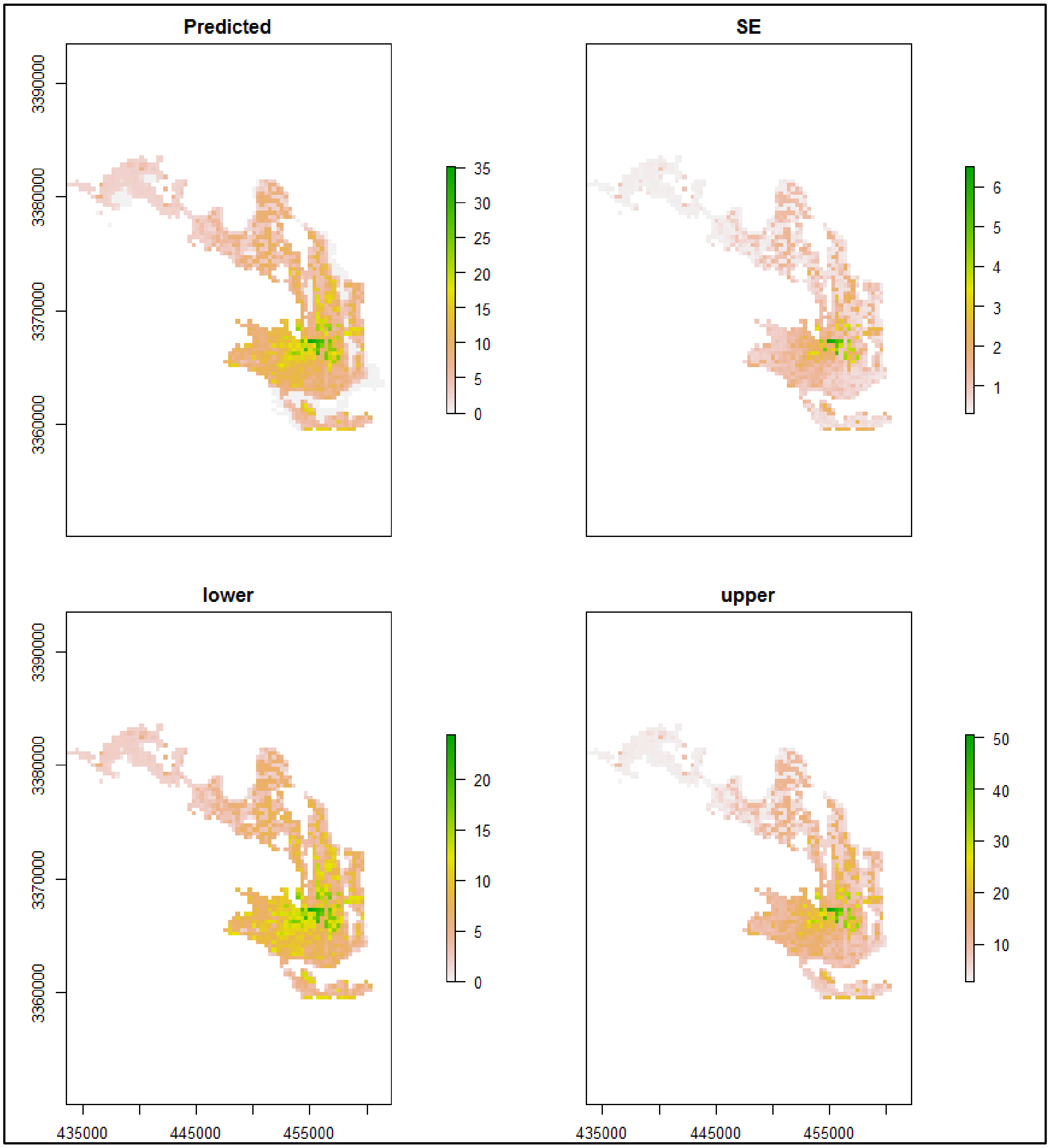

Figure E.10: Predicted clapper rail abundance in the pooled data sets under model fm2.

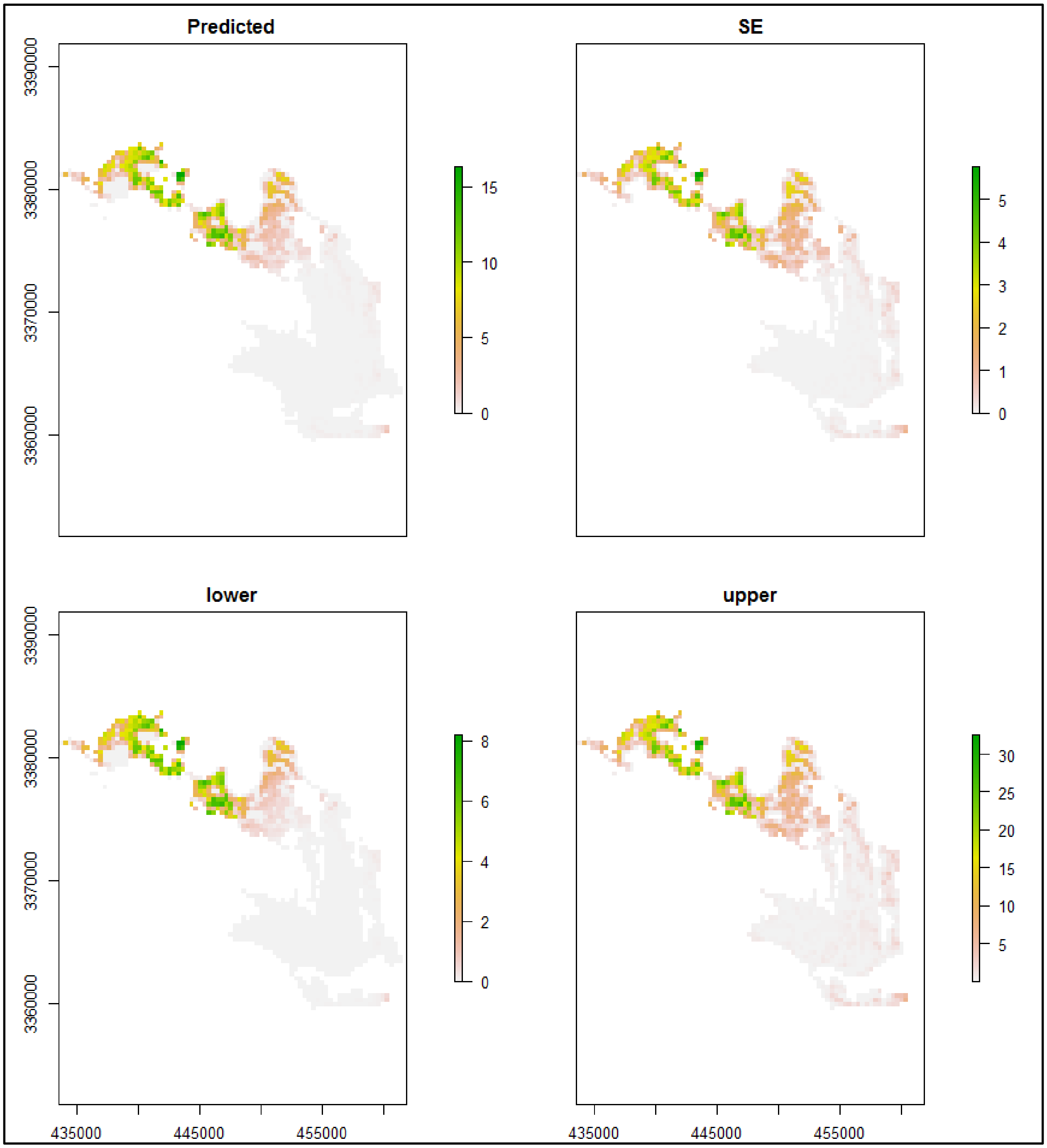

Figure E.11: Predicted KICL abundance in 2015 under model fm5.

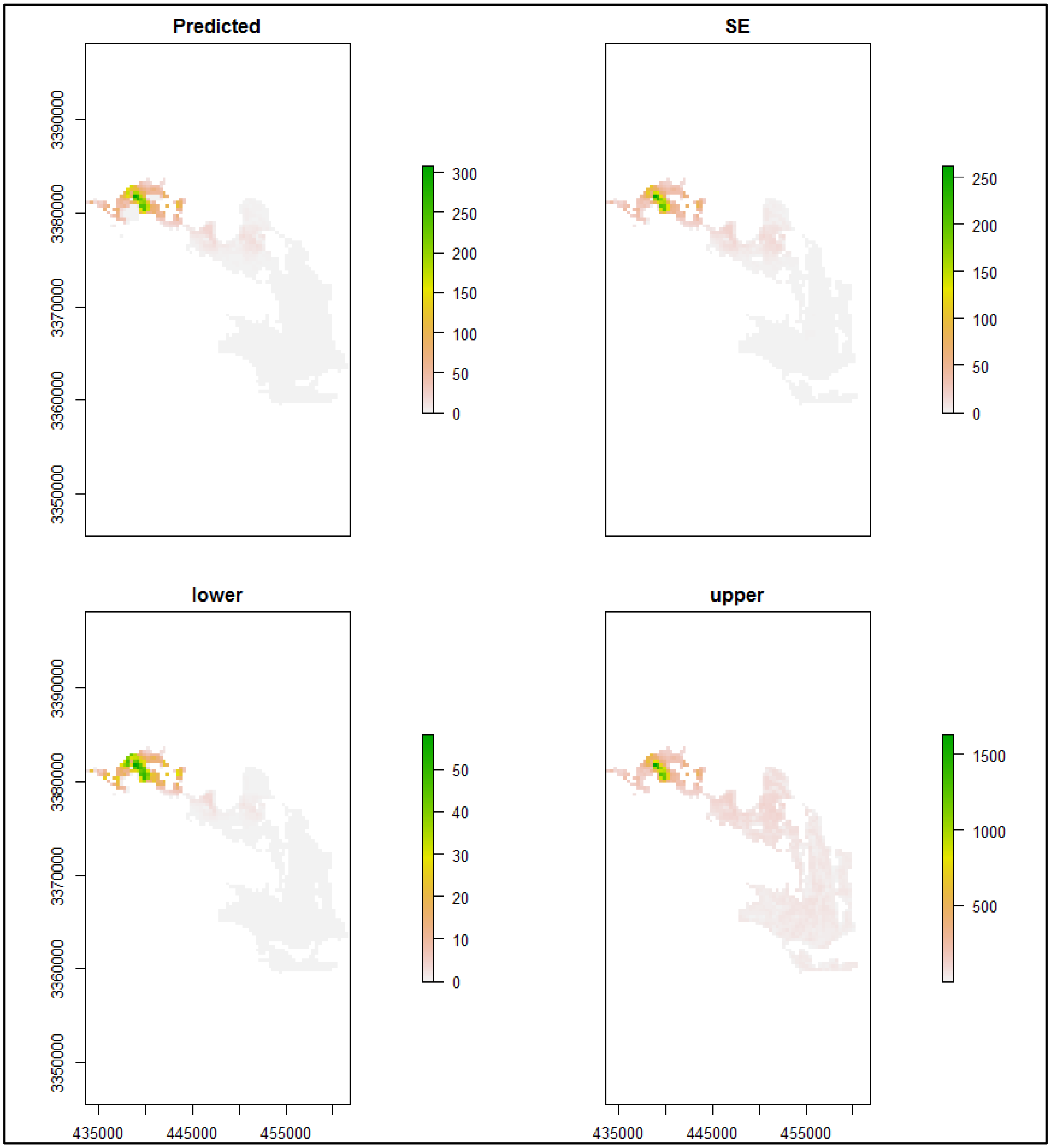

Figure E.12: Predicted KICL abundance in 2016 under model fm4.

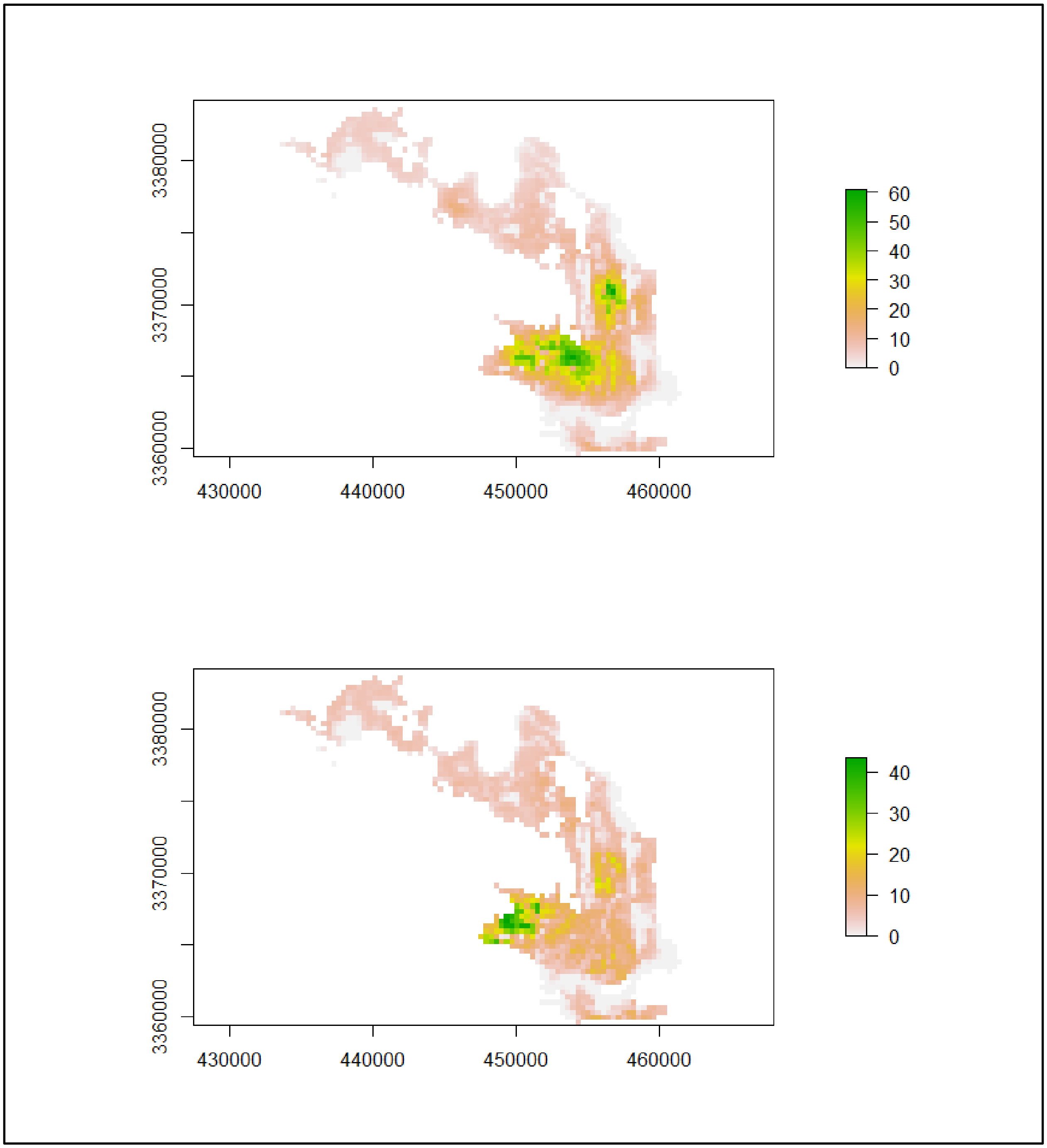

Figure E.13: Predicted KICL abundance for the pooled data set under model fm6ZP (top), and fm8ZP (bottom).

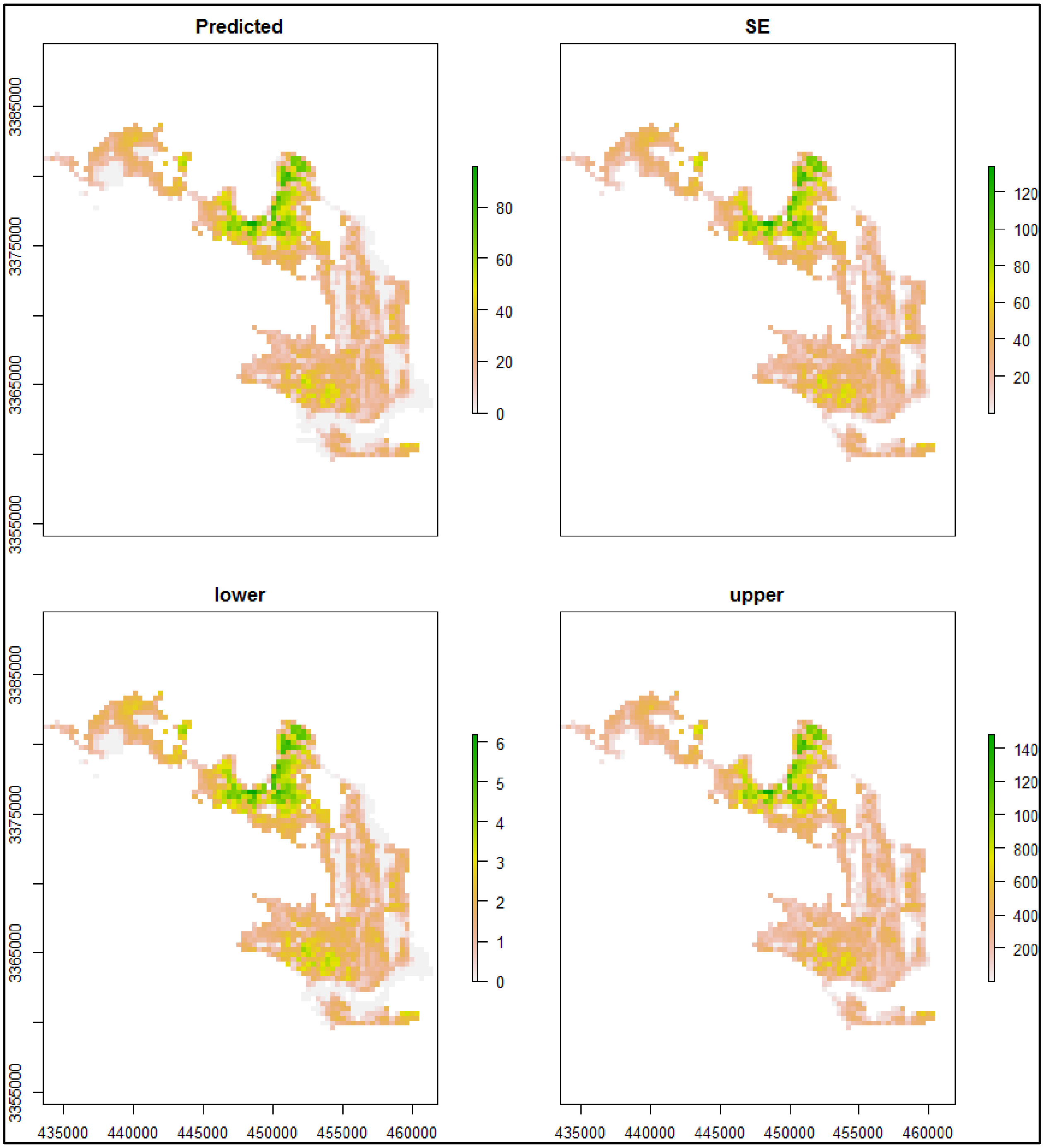

Figure E.14: Predicted marsh wren abundance for 2015 under model fm1.

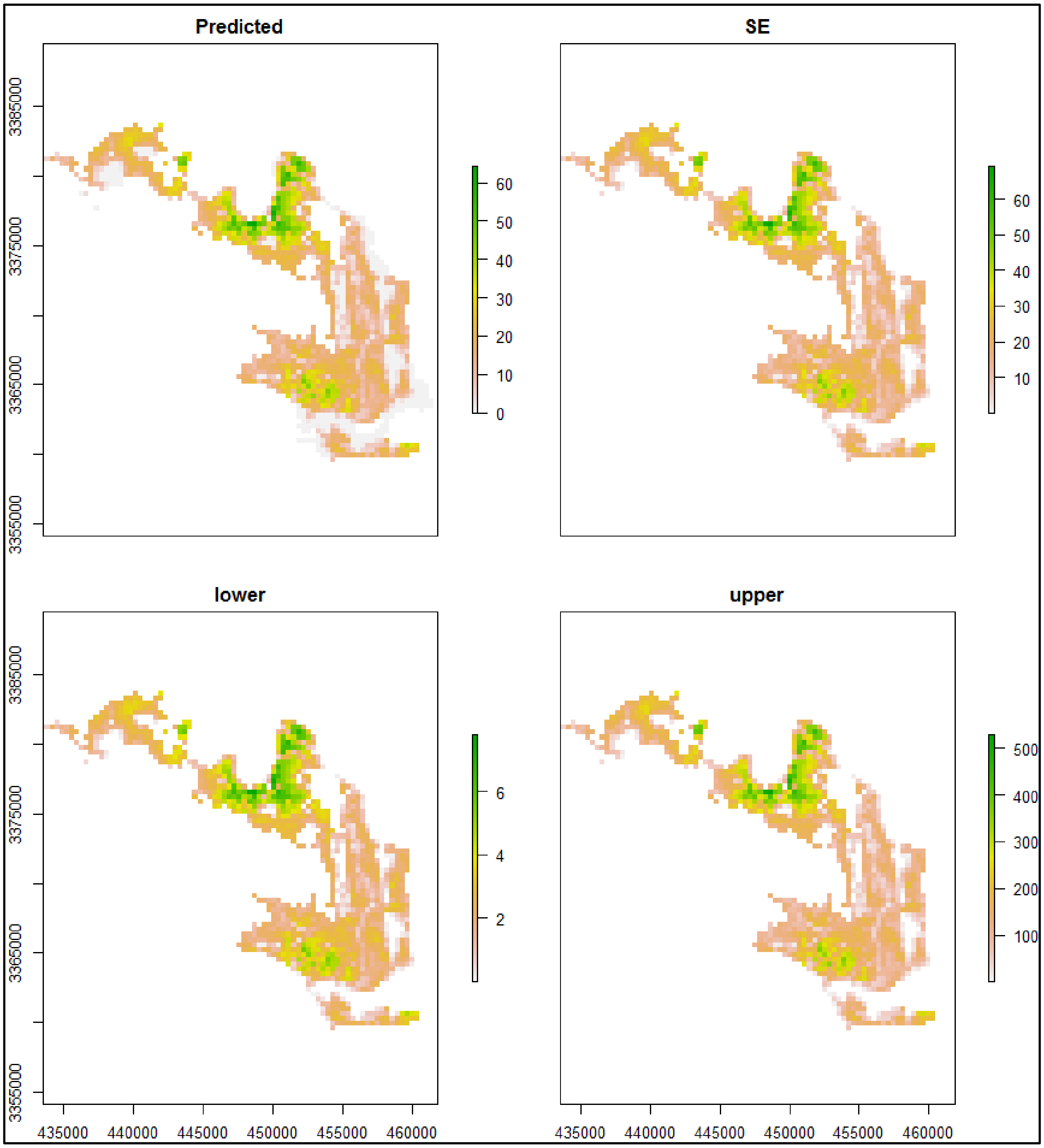

Figure E.15: Predicted marsh wren abundance for 2015 under model fm6.

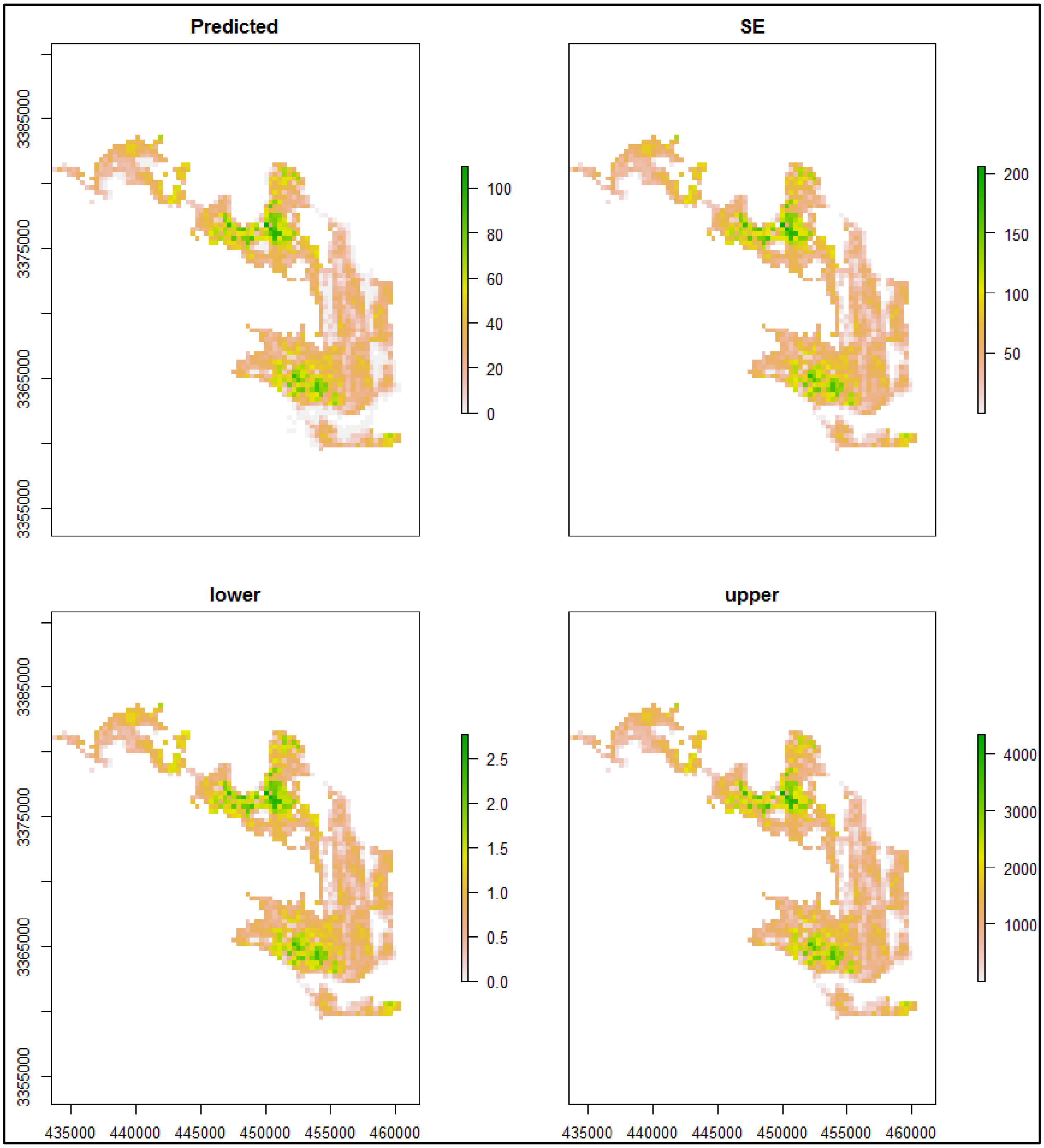

Figure E.16: Predicted marsh wren abundance for 2015 under model fm9.

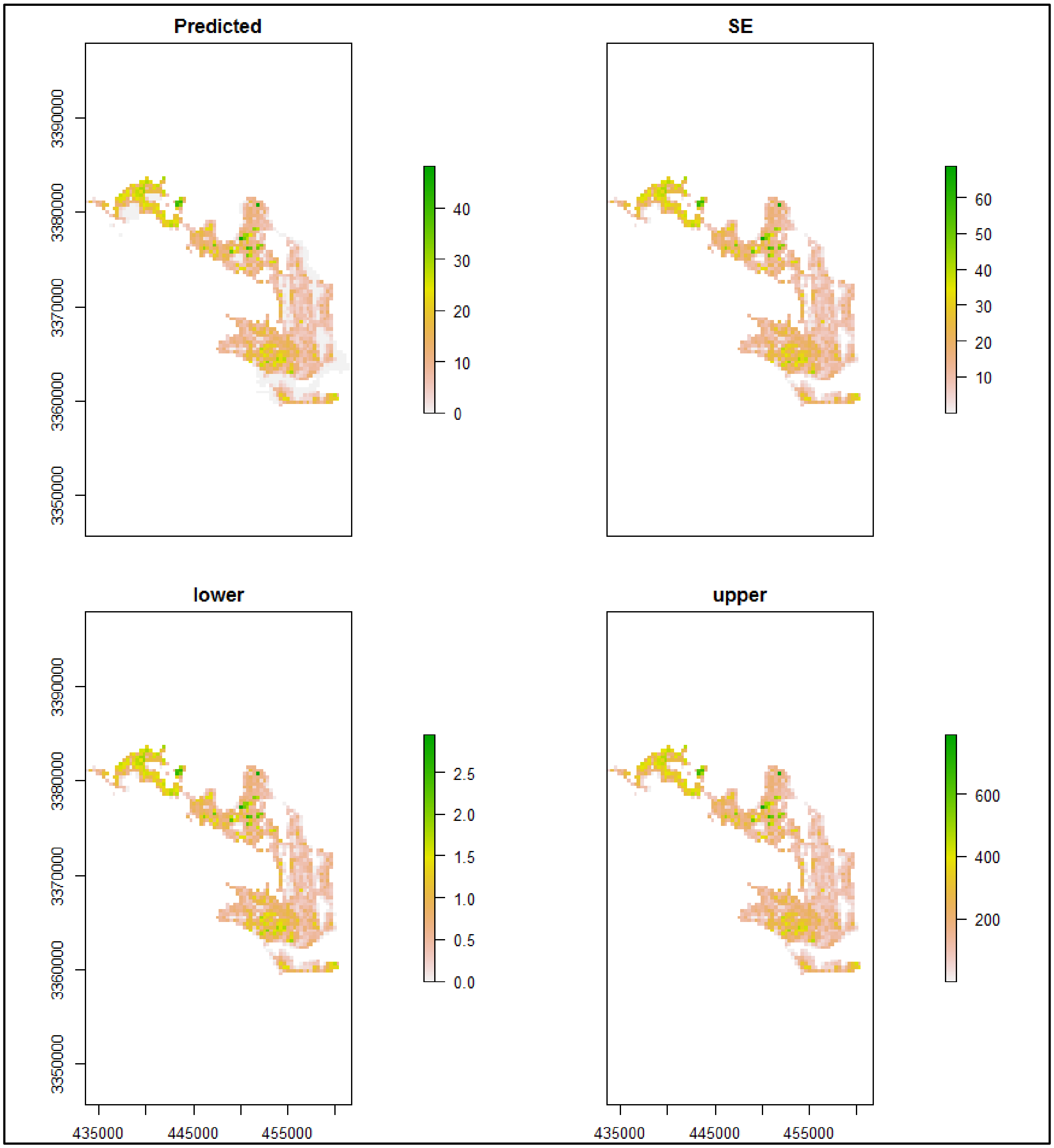

Figure E.17: Predicted marsh wren abundance for 2016 under model fm1.

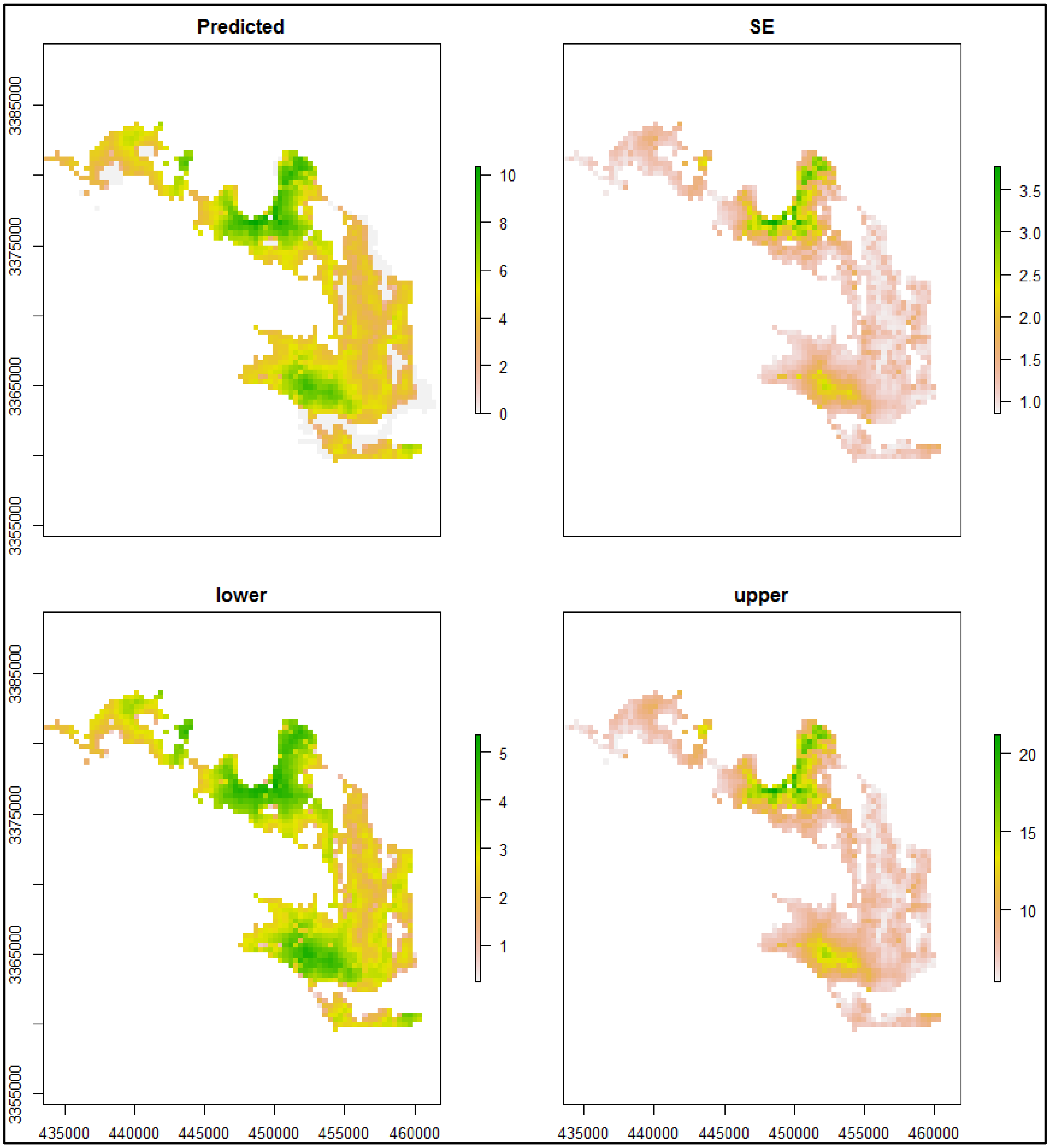

Figure E.18: Predicted marsh wren abundance for the pooled data set under model fm1.

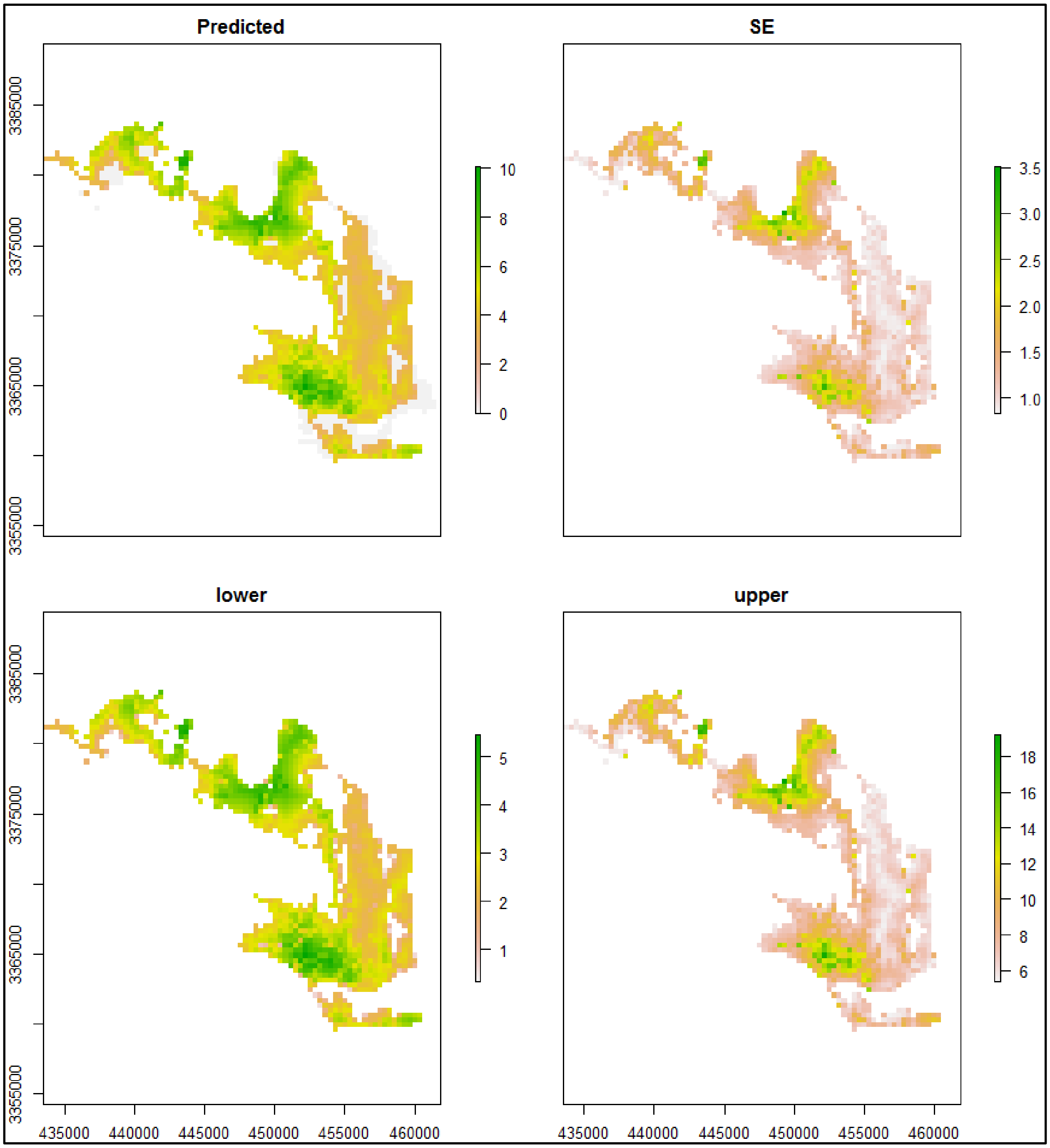

Figure E.19: Predicted marsh wren abundance for the pooled data set under model fm6.

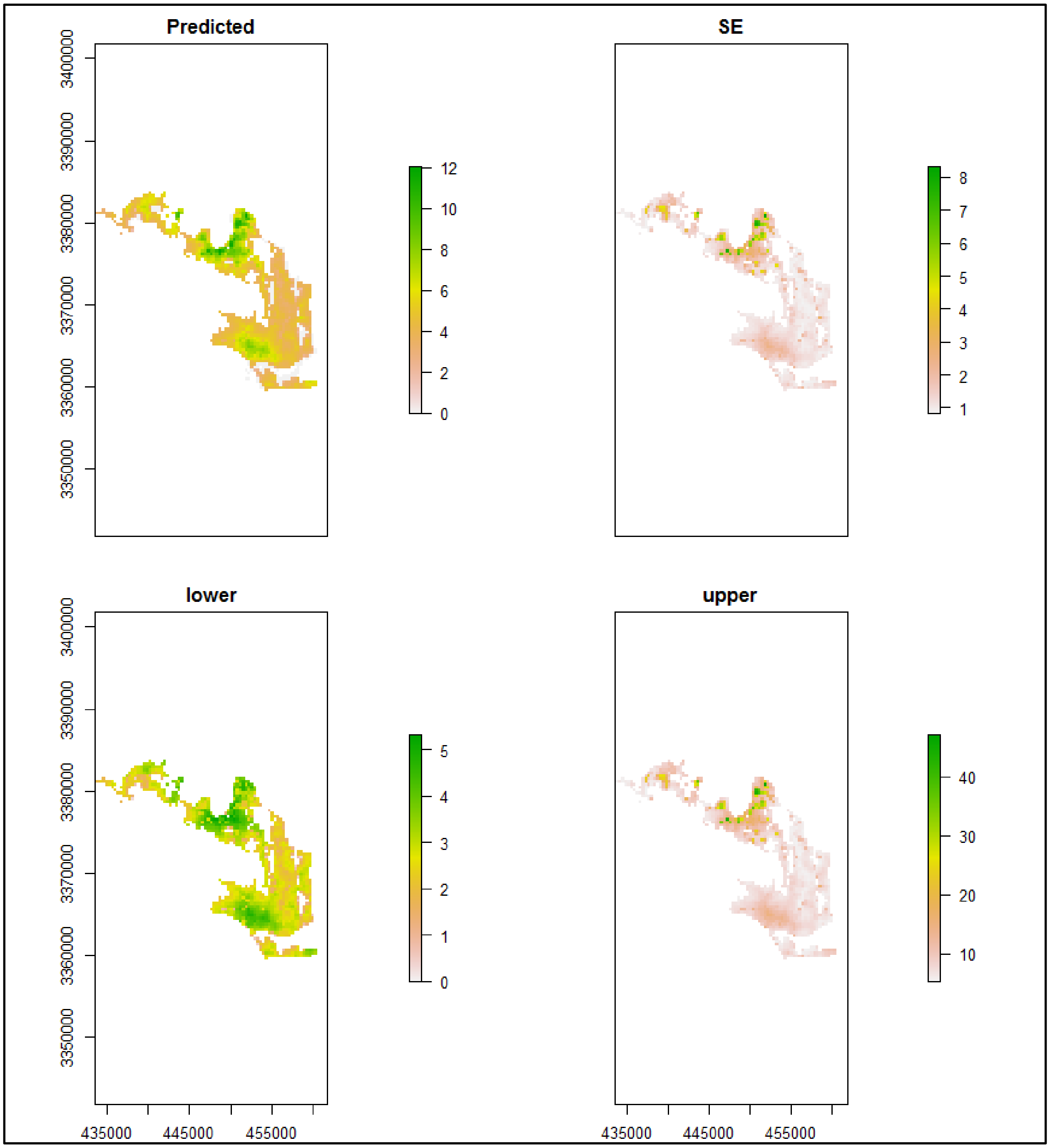

Figure E.20: Predicted marsh wren abundance for the pooled data set under model fm9.

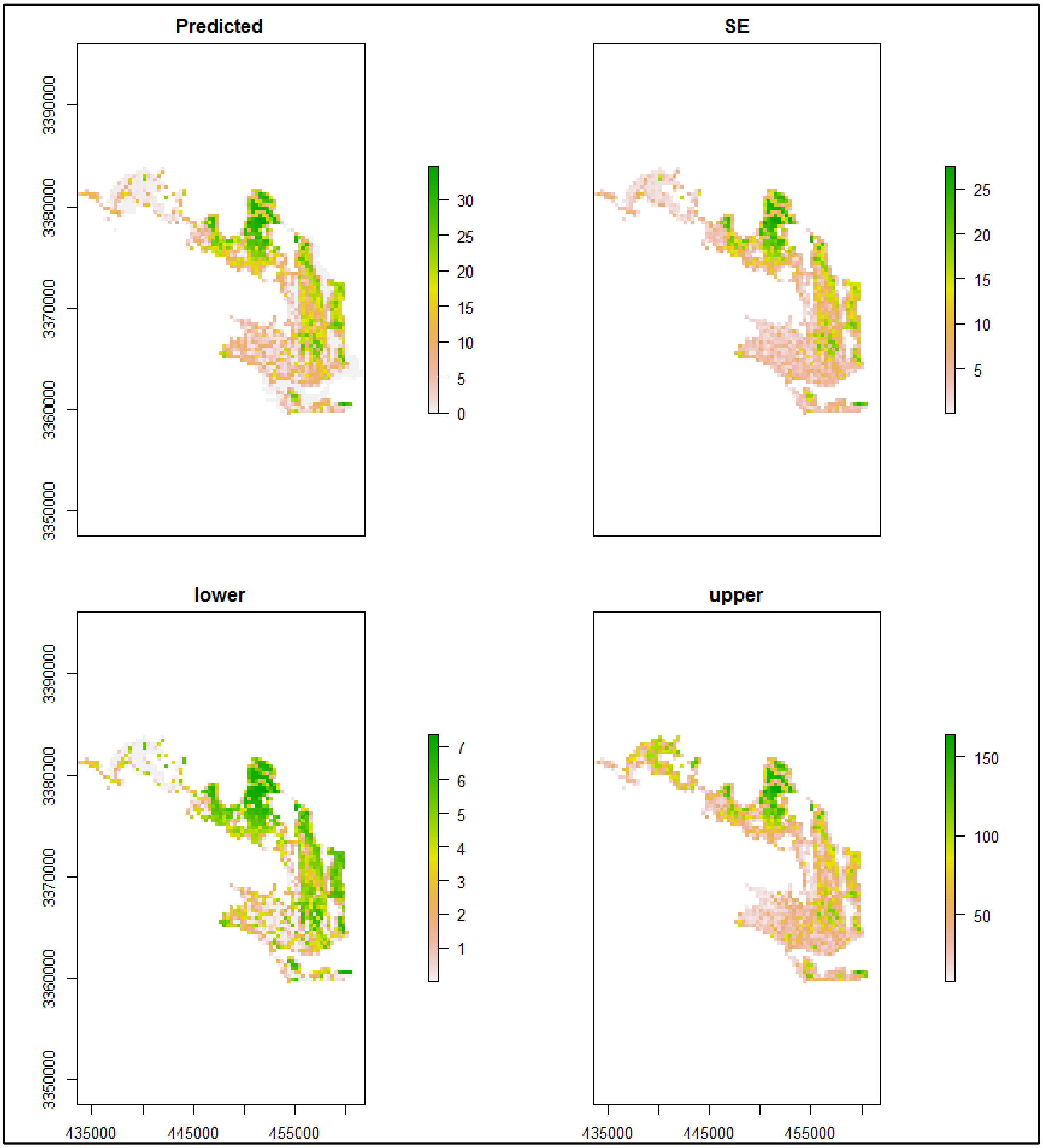

Figure E.21: Predicted seaside sparrow abundance for 2015 under model fm4.

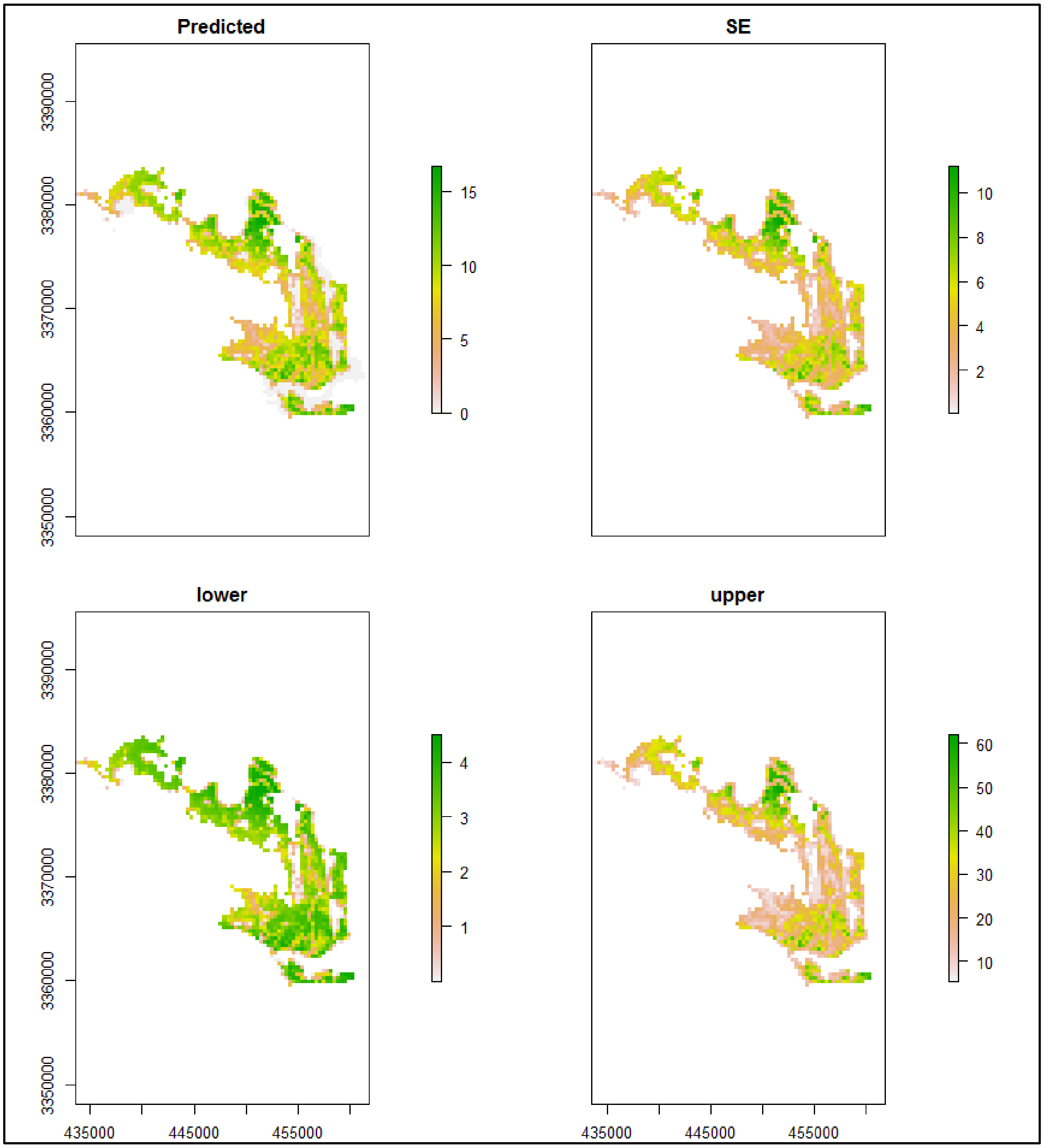

Figure E.22: Predicted seaside sparrow abundance for 2015 under model fm6.

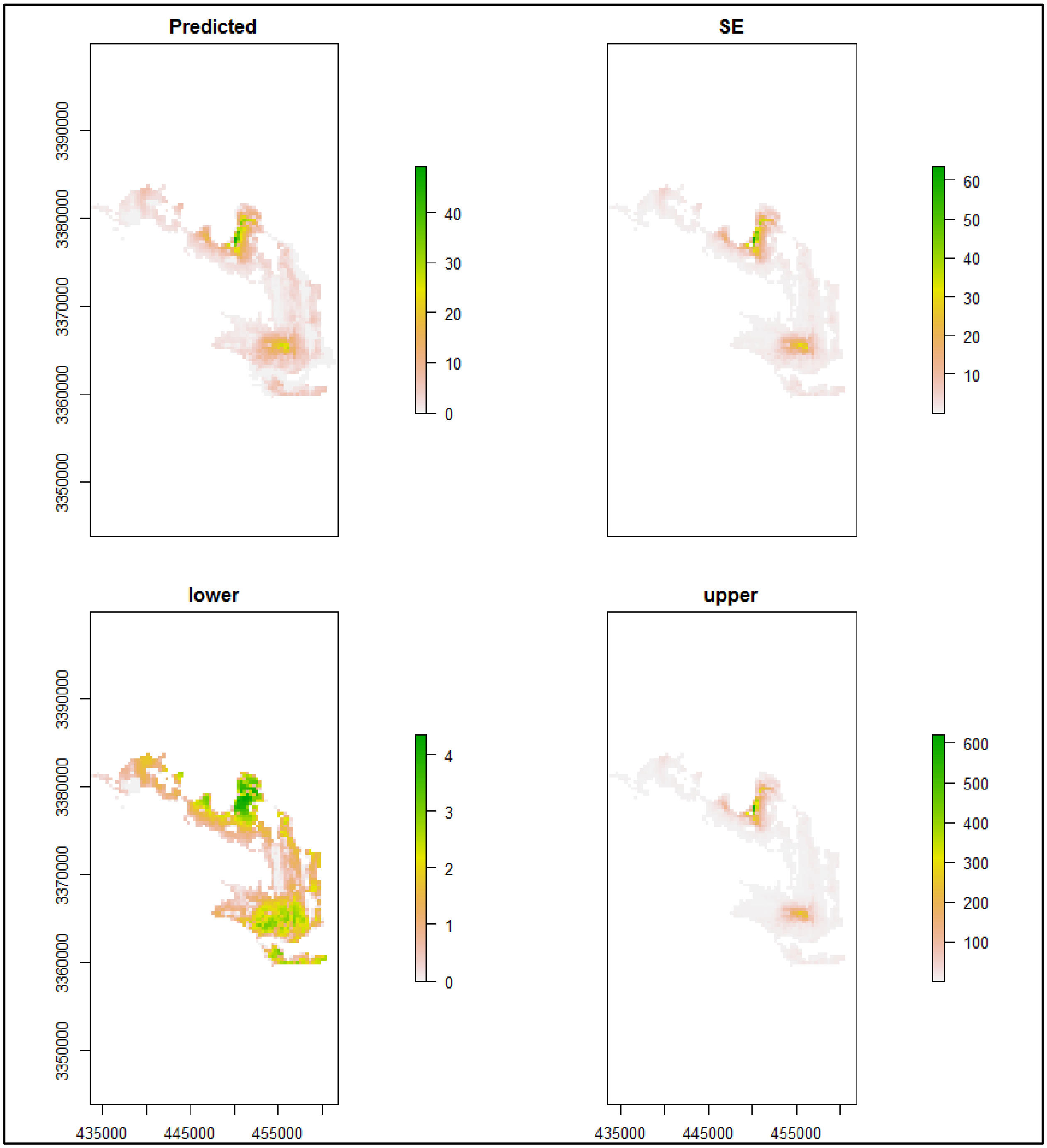

Figure E.23: Predicted seaside sparrow abundance for 2016 under model fm6.

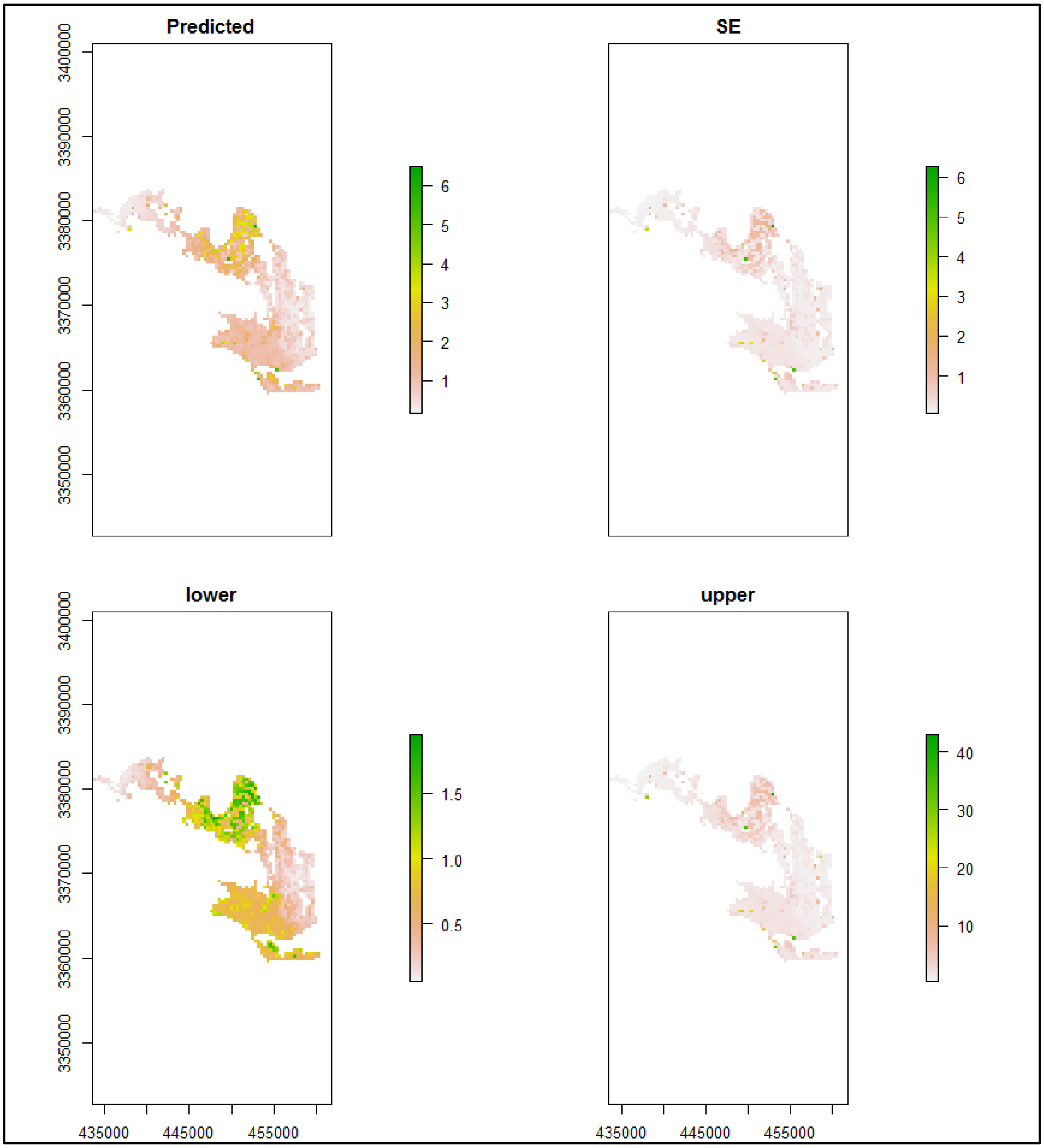

Figure E.24: Predicted seaside sparrow abundance for the pooled set under model fm10.

APPENDIX F: BIOLOGICAL COLLECTION FIGURES FOR CLAPPER RAILS AND INVERTEBRATES

Appendix F contains figures depicting the sample collection process for metal analyses in this study.

Figure F.1: Net placement and height of nets used to capture clapper rails during the 2015-2016 seasons within the Timucuan Ecological & Historic Preserve.

Figure F.2: Staking down nets used to capture clapper rails during the 2015-2016 seasons within the Timucuan Ecological & Historic Preserve.

Figure F.3: Location of personnel at the endpoints of the nets used to capture clapper rails during the 2015-2016 seasons within the Timucuan Ecological & Historic Preserve.

Figure F.4: Blood collection from the right jugular vein in an adult clapper rail captured in 2016 within the Timucuan Ecological & Historic Preserve.

Figure F.5: Blood collection from the right jugular vein in an HY clapper rail captured in 2015 within the Timucuan Ecological & Historic Preserve.

Figure F.6: Example of composite invertebrate samples (Sesarma spp. top, Ilyanassa spp. bottom) collected within the Timucuan Ecological & Historic Preserve during 2015-2016.

APPENDIX G: QAQC PROTCOLS FOR METAL ANALYSIS

Appendix G details the QAQC procedures used in the metal analysis in this study.

analyzed. Ratios of the internal standards responses against each other should also be monitored routinely. This information may be used to detect potential problems caused by mass dependent drift, errors incurred in adding the internal standards or increases in the concentrations of individual internal standards caused by background contributions from the sample. The absolute response of any one internal standard must not deviate more than 60-125% of the original response in the calibration blank. If deviations greater than these are observed, flush the instrument with the rinse blank and monitor the responses in the calibration blank. If the responses of the internal standards are now within the limit, take a fresh aliquot of the sample, dilute by a further factor of two, add the internal standards and reanalyze. If after flushing the response of the internal standards in the calibration blank are out of limits, terminate the analysis and determine the cause of the drift. Possible causes of drift may be a partially blocked sampling cone or a change in the tuning condition of the instrument.

10.0 CALIBRATION AND STANDARDIZATION

10.1 Operating conditions - Because of the diversity of instrument hardware, no detailed instrument operating conditions are provided. The analyst is advised to follow the recommended operating conditions provided by the manufacturer. It is the responsibility of the analyst to verify that the instrument configuration and operating conditions satisfy the analytical requirements and to maintain quality control data verifying instrument performance and analytical results. Instrument operating conditions which were used to generate precision and recovery data for this method (Section 13.0) are included in Table 6.

10.2 Precalibration routine - The following precalibration routine must be completed prior to calibrating the instrument until such time it can be documented with periodic performance data that the instrument meets the criteria listed below without daily tuning.

10.2.1 Initiate proper operating configuration of instrument and data system. Allow a period of not less than 30 minutes for the instrument to warm up. During this process conduct mass calibration and resolution checks using the tuning solution. Resolution at low mass is indicated by magnesium isotopes 24, 25, and 26. Resolution at high mass is indicated by lead isotopes 206, 207, and 208. For good performance adjust spectrometer resolution to produce a peak width of approximately 0.75 amu at 5% peak height. Adjust mass calibration if it has shifted by more than 0.1 amu from unit mass.

10.2.2 Instrument stability must be demonstrated by running the tuning solution (Section 7.7) a minimum of five times with resulting relative standard deviations of absolute signals for all analytes of less than 5%.

10.3 Internal Standardization - Internal standardization must be used in all analyses to correct for instrument drift and physical interferences. A list of acceptable

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Figure G.1: EPA method 3.052 calibration and standardization for metal analysis in this study.

9.4.1 Sample homogeneity and the chemical nature of the sample matrix can affect analyte recovery and the quality of the data. Taking separate aliquots from the sample for replicate and fortified analyses can in some cases assess the effect. Unless otherwise specified by the data user, laboratory or program, the following laboratory fortified matrix (LFM) procedure (Section 9.4.2) is required.

9.4.2 The laboratory must add a known amount of analyte to a minimum of 10% of the routine samples. In each case the LFM aliquot must be a duplicate of the aliquot used for sample analysis and for total recoverable determinations added prior to sample preparation. For water samples, the added analyte concentration must be the same as that used in the laboratory fortified blank (Section 7.9). For solid samples, the concentration added should be 100 mg/kg equivalent (200 µg/L in the analysis solution) except silver which should be limited to 50 mg/kg (Section 1.8). Over time, samples from all routine sample sources should be fortified.

9.4.3 Calculate the percent recovery for each analyte, corrected for background concentrations measured in the unfortified sample, and compare these values to the designated LFM recovery range of 70-130%. Recovery calculations are not required if the concentration of the analyte added is less than 30% of the sample background concentration. Percent recovery may be calculated in units appropriate to the matrix, using the following equation:

$$R = \frac{C_s - C}{s} \times 100$$

where:

R = percent recovery
C_s = fortified sample concentration
C = sample background concentration
s = concentration equivalent of analyte added to fortify the sample

9.4.4 If recovery of any analyte falls outside the designated range and laboratory performance for that analyte is shown to be in control (Section 9.3), the recovery problem encountered with the fortified sample is judged to be matrix related, not system related. The data user should be informed that the result for that analyte in the unfortified sample is suspect due to either the heterogeneous nature of the sample or an uncorrected matrix effect.

9.4.5 Internal standards responses - The analyst is expected to monitor the responses from the internal standards throughout the sample set being

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Figure G.2: EPA method 3.052 percent recovery for metal analysis in this study.

2.0 SUMMARY OF METHOD

2.1 An aliquot of a well mixed, homogeneous aqueous or solid sample is accurately weighed or measured for sample processing. For total recoverable analysis of a solid or an aqueous sample containing undissolved material, analytes are first solubilized by gentle refluxing with nitric and hydrochloric acids. After cooling, the sample is made up to volume, is mixed and centrifuged or allowed to settle overnight prior to analysis. For the determination of dissolved analytes in a filtered aqueous sample aliquot, or for the "direct analysis" total recoverable determination of analytes in drinking water where sample turbidity is <1 NTU, the sample is made ready for analysis by the appropriate addition of nitric acid, and then diluted to a predetermined volume and mixed before analysis.

2.2 The method describes the multi-element determination of trace elements by ICP-MS.[1-2] Sample material in solution is introduced by pneumatic nebulization into a radiofrequency plasma where energy transfer processes cause desolvation, atomization and ionization. The ions are extracted from the plasma through a differentially pumped vacuum interface and separated on the basis of their massto-charge ratio by a quadrupole mass spectrometer having a minimum resolution capability of 1 amu peak width at 5% peak height. The ions transmitted through the quadrupole are detected by an electron multiplier or Faraday detector and the ion information processed by a data handling system. Interferences relating to the technique (Section 4.0) must be recognized and corrected for. Such corrections must include compensation for isobaric elemental interferences and interferences from polyatomic ions derived from the plasma gas, reagents or sample matrix. Instrumental drift as well as suppressions or enhancements of instrument response caused by the sample matrix must be corrected for by the use of internal standards.

Figure G.3: Summary of EPA method 200.8 for metal analyses in this study.

APPENDIX H: SUMMARY OF PUBLISHED METAL VALUES FOR BIRDS AND INVERTEBRATES

Appendix H summarizes published blood metal levels for various avian species, and metal levels for selected invertebrate species.

Table H.1: Whole blood arsenic values in parts per million (ppm) w/w for select avian species and clapper rails in this study. Values are written as they appear in the literature, and values from this study are in boldface.

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Seeds	PSITTACINE*	---	0.078	0.093	Rosenthal et al., 2005	Adult	Captivity
Fish	OSPR	---	<0.004	0.348	Langner et al., 2012	Nestling/chick	Not Specified
Aquatic Inverts	AMAV	BMDL	---	---	Rhodes et al., 2015	Adult	Not Specified
Seeds	MODO	BMDL	---	---	Rhodes et al., 2015	Adult	Not Specified
Aquatic Inverts	COEI	0.0	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	LTDU	0.0	---	---	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	0.51	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	0.82	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	1.2	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	---	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	---	CEE-TV	Adult	Not Specified
Insects	TRSW	0.00095			Tsipoura et al., 2008	Adult	Not Specified
Aquatic Inverts	REPH	0.0013	ND	0.003	Hargreaves et al., 2011	Adult	Not Specified
Fish	WOST	0.00235	0.00091	0.0106	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Insects	MAWR	0.00373			Tsipoura et al., 2008	Adult	Not Specified
Insects	RWBL	0.00464			Tsipoura et al., 2008	Adult	Not Specified
Omnivore	FRGU	0.005	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	POCH	0.006	---	---	Benito et al., 1999	Adult	Not Specified
Fish	GCGR	0.006	---	---	Benito et al., 1999	Adult	Not Specified
Fish	GRAY HERON	0.006	---	---	Benito et al., 1999	Adult	Not Specified
Omnivore	GRFL	0.006	---	---	Benito et al., 1999	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	YLGU	0.006	---	---	Benito et al., 1999	Adult	Not Specified
Carnivore	BLKI	0.008	0.006	0.035	Benito et al., 1999	Adult	Not Specified
Insects	GLIB	0.008	0.006	0.017	Benito et al., 1999	Adult	Not Specified
Insects	WRSA	0.011	ND	0.19	Hargreaves et al., 2011	Adult	Not Specified
Seeds	MALL	0.011	0.006	0.042	Benito et al., 1999	Adult	Not Specified
Carnivore	COMMON BUZZARD	0.01489	ND	0.08508	Carneiro et al., 2014	Adult	Not Specified
Herbivore	GADW	0.017	0.006	0.029	Benito et al., 1999	Adult	Not Specified
Aquatic Inverts	RUTU	0.018	ND	0.23	Hargreaves et al., 2011	Adult	Not Specified
Omnivore	FRGU	0.018	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	SPOONBILL	0.019	0.006	0.181	Benito et al., 1999	Adult	Not Specified
Fish	WHST	0.019	0.006	0.121	Benito et al., 1999	Adult	Not Specified
Aquatic Inverts	BNST	0.02	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	BRTH	0.02	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	EATO	0.02	---	---	Rhodes et al., 2015	Adult	Not Specified
Fish	WOST	0.02248	0.00291	0.1081	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Fish	WOST	0.02304	0.0108	0.0319	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Carnivore	NOGO	0.025	---	---	Stout et al., 2010	Adult	Not Specified
Omnivore	HEGU	0.028	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.05**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Fish	BCNH	0.072	---	---	CEE-TV	Nestling/chick	Not Specified
Aquatic Inverts	SPEI	0.11	---	---	CEE-TV	Adult	Not Specified

Diet	**AOU Code**	**Mean**	**Low Range**	**High Range**	**Reference Source**	**Age**	**Site Status**
Insects	PIFL	0.11	---	---	Berglund and Nyholm, 2011	Adult	Reference Site
Fish	BCNH	0.111	---	---	CEE-TV	Nestling/chick	Not Specified
Aquatic Inverts	COEI	0.12	---	---	CEE-TV	Adult	Not Specified
Insects	PIFL	0.12	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Fish	BCNH	0.128	---	---	CEE-TV	Nestling/chick	Reference Site
Aquatic Inverts	SPEI	0.14	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	SPEI	0.14	---	---	CEE-TV	Nestling/chick	Not Specified
Aquatic Inverts	SPEI	0.15	---	---	CEE-TV	Adult	Not Specified
Omnivore	HEGU	0.166	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	PIFL	0.24	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.30	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.33	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Omnivore	HEGU	0.556	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	BFAL	0.62	0.22	1.6	Finkelstein et al., 2007	Adult	Not Specified
Omnivore	**CLRA**	**1.02**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**1.40**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	**CLRA**	**1.78**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**1.92**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**2.45**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**2.57**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**2.80**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	EATO	---	BMDL	0.02	Rhodes et al., 2015	Adult	Not Specified
Omnivore	**CLRA**	**4.62**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**7.35**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**7.84**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**9.52**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**9.60**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**11.03**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**15.51**	**---**	**---**	**This study**	**Adult**	**Not Specified**

Table H.2: Whole blood cadmium values in parts per million (ppm) w/w for select avian species and clapper rails in this study. Values are written as they appear in the literature, and values from this study are in boldface.

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	BRTH	---	---	0.029	Rhodes et al., 2015	Adult	Not Specified
Omnivore	BRTH	---	---	0.414	Rhodes et al., 2015	Adult	Not Specified
Omnivore	EATO	---	---	0.011	Rhodes et al., 2015	Adult	Not Specified
Omnivore	NOMO	---	---	0.017	Rhodes et al., 2015	Adult	Not Specified
Aquatic Inverts	BNST	---	---	0.005	Rhodes et al., 2015	Adult	Not Specified
Seeds	MALL	---	0.0	0.1	Binkowski and Meissner, 2013	Adult	Contaminated Site
Seeds	MALL	---	0.0	1.1	Binkowski and Meissner, 2013	Adult	Reference Site
Seeds	MODO	---	---	0.016	Rhodes et al., 2015	Adult	Not Specified
Seeds	NOCA	---	---	0.004	Rhodes et al., 2015	Adult	Not Specified
Insects	RWBL	---	---	0.006	Rhodes et al., 2015	Adult	Not Specified
Insects	SAVS	---	---	0.161	Rhodes et al., 2015	Adult	Not Specified
Fish	WOST	---	4.3	5.3	Kaminski et al., 2007	Adult	Contaminated Site
Not Specified	BIRD	---	---	>0.26	Rhodes et al., 2015	Not Specified	Not Specified
Insects	DUNL	ND	---	---	Hargreaves et al., 2011	Adult	Not Specified
Insects	WRSA	ND	---	---	Hargreaves et al., 2011	Adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	WOST	<0.25	<0.25	<0.25	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Aquatic Inverts	LTDU	0	---	---	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	---	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	0.05	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	0.06	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	0.05	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.05**	**---**	**---**	**This study**	Adult	Not Specified
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Not Specified
Fish	GCGR	0.0001	---	---	Benito et al., 1999	Adult	Not Specified
Fish	GRAY HERON	0.0002	0.0001	0.001	Benito et al., 1999	Adult	Not Specified
Omnivore	YLGU	0.0002	0.0001	0.0005	Benito et al., 1999	Adult	Not Specified
Fish	SPOONBILL	0.0003	0.0001	0.001	Benito et al., 1999	Adult	Not Specified
Fish	WOST	0.00049	0.0004	0.00058	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Aquatic Inverts	EURASIAN OYSTERCATCHER	0.0005	ND	0.002	Hargreaves et al., 2011	Adult	Contaminated Site
Herbivore	GADW	0.0006	0.0001	0.029	Benito et al., 1999	Adult	Not Specified
Omnivore	GRFL	0.0006	0.0001	0.001	Benito et al., 1999	Adult	Not Specified
Aquatic Inverts	POCH	0.0009	0.0001	0.003	Benito et al., 1999	Adult	Not Specified
Insects	PIFL	0.001	---	---	Berglund and Nyholm, 2011	Adult	Reference Site
Fish	WHST	0.0015	0.0001	0.009	Benito et al., 1999	Adult	Not Specified
Insects	PIFL	0.002	---	---	Berglund and Nyholm, 2011	Adult	Reference Site
Insects	SOSP	0.002	---	---	Lester and Riper, 2014	Adult	Reference Site
Insects	SOSP	0.002	---	---	Lester and Riper, 2014	Adult	Not Specified
Fish	BAEA	0.002	---	---	CEE-TV	Juv/sub adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Carnivore	COMMON BUZZARD	0.00201	ND	0.04447	Carneiro et al., 2014	Adult	Not Specified
Insects	PIFL	0.003	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.003	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	TRSW	0.00358			Tsipoura et al., 2008	Adult	Not Specified
Insects	PIFL	0.004	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.004	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	SOSP	0.004	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	SOSP	0.004	---	---	Lester and Riper, 2014	Adult	Contaminated Site
Insects	SOSP	0.004	---	---	Lester and Riper, 2014	Adult	Not Specified
Seeds	MALL	0.0048	0.0001	0.019	Benito et al., 1999	Adult	Not Specified
Insects	SOSP	0.005	---	---	Lester and Riper, 2014	Adult	Not Specified
Omnivore	FRGU	0.006	---	---	CEE-TV	Adult	Not Specified
Carnivore	BLKI	0.0068	0.001	0.014	Benito et al., 1999	Adult	Not Specified
Insects	PIFL	0.007	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Omnivore	HEGU	0.009	---	---	CEE-TV	Juv/sub adult	Not Specified
Aquatic Inverts	KIEI	0.0095	0.0019	0.0758	Wayland et al., 2008	Adult	Not Specified
Insects	GLIB	0.011	0.006	0.015	Benito et al., 1999	Adult	Not Specified
Fish	BCNH	0.011	---	---	CEE-TV	Nestling/chick	Reference Site
Fish	BFAL	0.013	0.0081	0.031	Finkelstein et al., 2007	Adult	Not Specified
Insects	RWBL	0.0135			Tsipoura et al., 2008	Adult	Not Specified

Diet	**AOU Code**	**Mean**	**Low Range**	**High Range**	**Reference Source**	**Age**	**Site Status**
Insects	PIFL	0.014	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.015	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.016	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Omnivore	HEGU	0.016	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	SPEI	0.02	---	---	Wilson et al., 2004	Adult	Not Specified
Fish	WOST	0.02327	0.00552	0.1195	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Carnivore	NOGO	0.025	---	---	Stout et al., 2010	Adult	Not Specified
Insects	MAWR	0.0269			Tsipoura et al., 2008	Adult	Not Specified
Aquatic Inverts	KIEI	0.03	---	---	Wilson et al., 2004	Adult	Not Specified
Aquatic Inverts	SPEI	0.03	---	---	Wilson et al., 2004	Adult	Not Specified
Aquatic Inverts	SPEI	0.03	---	---	Wilson et al., 2004	Adult	Not Specified
Aquatic Inverts	SPEI	0.04	---	---	Wilson et al., 2004	Adult	Not Specified
Fish	LMSA	0.0428	0.029	0.0566	Summers et al., 2014	Adult	Not Specified
Omnivore	HEGU	0.047	---	---	CEE-TV	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**0.05**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**0.05**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**0.05**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**1.42**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**1.52**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**0.00**	**---**	**---**	**This study**	**Juv/sub adult**	Not Specified
Omnivore	**CLRA**	**0.05**	**---**	**---**	**This study**	**Juv/sub adult**	Not Specified
Aquatic Inverts	SPEI	0.05	---	---	Wilson et al., 2004	Nestling/chick	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	FRGU	0.099	---	---	CEE-TV	Juv/sub adult	Not Specified
Aquatic Inverts	SPEI	0.10	---	---	CEE-TV	Adult	Not Specified
Fish	BCNH	0.102	---	---	CEE-TV	Nestling/chick	Not Specified
Fish	NGPE	0.1941	0.159	0.2588	Summers et al., 2014	Adult	Not Specified
Fish	DMSA	0.1981	0.0162	0.3013	Summers et al., 2014	Adult	Not Specified
Omnivore	**CLRA**	**0.05**	**---**	**---**	**This study**	**Juv/sub adult**	Not Specified
Aquatic Inverts	SPEI	0.21	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.05**	**---**	**---**	**This study**	**Juv/sub adult**	Not Specified
Fish	MACARONI PENGUIN	0.2119	0.0373	0.4623	Summers et al., 2014	Adult	Not Specified
Fish	SGPE	0.2519	0.0649	0.5386	Summers et al., 2014	Adult	Not Specified
Aquatic Inverts	SPEI	0.27	---	---	CEE-TV	Nestling/chick	Not Specified
Fish	ROCKHOPPER PENGUIN	0.2711	0.0242	0.6923	Summers et al., 2014	Adult	Not Specified
Fish	KING PENGUIN	0.276	0.0084	0.9712	Summers et al., 2014	Adult	Not Specified
Omnivore	**CLRA**	**0.20**	**---**	**---**	**This study**	**Juv/sub adult**	Not Specified
Fish	WAAL	0.3219	0.1106	0.5338	Summers et al., 2014	Adult	Not Specified
Fish	CROZET SHAG	0.3534	0.0035	0.7511	Summers et al., 2014	Adult	Not Specified
Omnivore	**CLRA**	**0.21**	**---**	**---**	**This study**	**Juv/sub adult**	Not Specified
Omnivore	**CLRA**	**0.31**	**---**	**---**	**This study**	**Juv/sub adult**	Not Specified
Fish	SOTE	0.85	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	KIEI	0.97	---	---	Wilson et al., 2004	Adult	Not Specified
Omnivore	**CLRA**	**0.37**	**---**	**---**	**This study**	**Juv/sub adult**	Not Specified
Omnivore	**CLRA**	**0.55**	**---**	**---**	**This study**	**Juv/sub adult**	Not Specified
Aquatic Inverts	EURASIAN OYSTERCATCHER	2.0	ND	0.004	Hargreaves et al., 2011	Adult	Reference Site
Carnivore	BLVU	7.25	2.0	12	Bravo and Colina, 2005	Adult	Not Specified

Table H.3: Whole blood chromium values in parts per million (ppm) w/w for select avian species and clapper rails in this study. Values are written as they appear in the literature, and values from this study are in boldface.

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Seeds	MALL	---	0.0	0.45	Binkowski and Meissner, 2013	Adult	Contaminated Site
Seeds	MALL	---	0.0	0.16	Binkowski and Meissner, 2013	Adult	Reference Site
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Not Specified
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Reference Site
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Not Specified
Insects	EABL	0.00	0.00	0.00	McQuiston, 2002	Nestling/chick	Contaminated Site
Insects	EABL	0.00	0.00	0.00	McQuiston, 2002	Nestling/chick	Not Specified
Insects	TRSW	0.00	0.00	0.00	McQuiston, 2002	Nestling/chick	Contaminated Site
Insects	TRSW	0.00	0.00	0.00	McQuiston, 2002	Nestling/chick	Not Specified
Insects	SOSP	0.018	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	SOSP	0.023	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	SOSP	0.035	---	---	Lester and Riper, 2014	Adult	Reference Site
Insects	SOSP	0.047	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	SOSP	0.12	---	---	Lester and Riper, 2014	Adult	Contaminated Site
Seeds	MODO	0.18	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	HEGU	0.197	---	---	CEE-TV	Adult	Not Specified
Omnivore	HEGU	0.207	---	---	CEE-TV	Juv/sub adult	Not Specified
Aquatic Inverts	BNST	0.23	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	BRTH	0.23	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	FRGU	0.236	---	---	CEE-TV	Juv/sub adult	Not Specified
Aquatic Inverts	AMAV	0.24	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	EATO	0.26	---	---	Rhodes et al., 2015	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	FRGU	0.274	---	---	CEE-TV	Adult	Not Specified
Omnivore	HEGU	0.353	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	MAWR	0.505			Tsipoura et al., 2008	Adult	Not Specified
Insects	RWBL	0.518			Tsipoura et al., 2008	Adult	Not Specified
Omnivore	**CLRA**	**0.54**	**---**	**---**	**This study**	Juv/sub adult	Not Specified
Omnivore	EATO	0.72	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	**CLRA**	**0.89**	**---**	**---**	**This study**	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**0.93**	**---**	**---**	**This study**	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**0.99**	**---**	**---**	**This study**	Juv/sub adult	Not Specified
Insects	TRSW	1.030			Tsipoura et al., 2008	Adult	Not Specified
Omnivore	**CLRA**	**1.35**	**---**	**---**	**This study**	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**1.52**	**---**	**---**	**This study**	Juv/sub adult	Not Specified
Insects	SOSP	2.145	---	---	Lester and Riper, 2014	Adult	Not Specified
Omnivore	**CLRA**	**21.66**	**---**	**---**	**This study**	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**23.54**	**---**	**---**	**This study**	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**25.11**	**---**	**---**	**This study**	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**25.30**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**26.90**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**31.63**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**32.35**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**40.34**	**---**	**---**	**This study**	Adult	Not Specified
Omnivore	**CLRA**	**50.13**	**---**	**---**	**This study**	Adult	Not Specified

Table H.4: Whole blood copper values in parts per million (ppm) w/w for select avian species and clapper rails in this study. Values are written as they appear in the literature, and values from this study are in boldface.

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Seeds	MALL	---	0.01	2.9	Binkowski and Meissner, 2013	Adult	Contaminated Site
Seeds	MALL	---	0.5	6.5	Binkowski and Meissner, 2013	Adult	Reference Site
Seeds	PSITTACINE	---	0.124	0.142	Rosenthal et al., 2005	Adult	Captivity
Fish	OSPR	---	0.179	0.430	Langner et al., 2012	Nestling/chick	Not Specified
Fish	RTLO	0.0	---	---	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	0.44	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	0.50	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	0.45	CEE-TV	Adult	Not Specified
Fish	RTLO	0.0	---	0.41	CEE-TV	Adult	Not Specified
Insects	GLIB	0.133	0.067	0.241	Benito et al., 1999	Adult	Not Specified
Insects	PIFL	0.16	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.20	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.20	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Aquatic Inverts	POCH	0.203	0.151	0.396	Benito et al., 1999	Adult	Not Specified
Carnivore	BLKI	0.211	0.12	0.303	Benito et al., 1999	Adult	Not Specified
Insects	PIFL	0.22	---	---	Berglund and Nyholm, 2011	Adult	Reference Site
Insects	PIFL	0.23	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Omnivore	FLAMINGO	0.25	0.13	0.51	Eisler, 2010	Nestling/chick	Not Specified
Seeds	MALL	0.258	0.142	0.361	Benito et al., 1999	Adult	Not Specified
Fish	BFALBA	0.27	0.18	0.43	Finkelstein et al., 2007	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Aquatic Inverts	AMAV	0.29	---	---	Rhodes et al., 2015	Adult	Not Specified
Fish	SPOONBILL	0.307	0.19	0.569	Benito et al., 1999	Adult	Not Specified
Omnivore	GRFL	0.334	0.187	0.531	Benito et al., 1999	Adult	Not Specified
Herbivore	GRAY HERON	0.352	0.204	0.65	Benito et al., 1999	Adult	Not Specified
Omnivore	EATO	0.36	---	---	Rhodes et al., 2015	Adult	Not Specified
Fish	BCNH	0.379	---	---	CEE-TV	Nestling/chick	Reference Site
Fish	GCGR	0.395	0.327	0.488	Benito et al., 1999	Adult	Not Specified
Carnivore	NOGO	0.399	0.294	0.488	Stout et al., 2010	Adult	Not Specified
Fish	BCNH	0.408	---	---	CEE-TV	Nestling/chick	Not Specified
Fish	BCNH	0.425	---	---	CEE-TV	Nestling/chick	Not Specified
Omnivore	YLGU	0.429	0.271	0.535	Benito et al., 1999	Adult	Not Specified
Aquatic Inverts	LESC	0.43	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	BNST	0.5	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	BRTH	0.5	---	---	Rhodes et al., 2015	Adult	Not Specified
Herbivore	GADW	0.526	0.346	0.753	Benito et al., 1999	Adult	Not Specified
Omnivore	EATO	0.53	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	**CLRA**	**0.55**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	SOSP	0.578	---	---	Lester and Riper, 2014	Adult	Not Specified
Fish	WHST	0.586	0.18	1.53	Benito et al., 1999	Adult	Not Specified
Omnivore	**CLRA**	**0.64**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	SOSP	0.672	---	---	Lester and Riper, 2014	Adult	Reference Site
Insects	SOSP	0.699	---	---	Lester and Riper, 2014	Adult	Contaminated Site
Insects	SOSP	0.74	---	---	Lester and Riper, 2014	Adult	Not Specified
Omnivore	**CLRA**	**0.74**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	SOSP	0.811	---	---	Lester and Riper, 2014	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	SOSP	1.118	---	---	Lester and Riper, 2014	Adult	Not Specified
Omnivore	**CLRA**	**1.26**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Insects	EABL	1.67	1.14	2.45	McQuiston, 2002	Nestling/chick	Contaminated Site
Insects	EABL	1.67	1.3	2.16	McQuiston, 2002	Nestling/chick	Not Specified
Insects	TRSW	1.82	0.72	4.58	McQuiston, 2002	Nestling/chick	Contaminated Site
Omnivore	**CLRA**	**1.97**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**2.35**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**3.01**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**3.03**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Insects	TRSW	3.12	2.34	4.16	McQuiston, 2002	Nestling/chick	Not Specified
Omnivore	**CLRA**	**3.16**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**4.02**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**4.62**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**5.97**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**6.03**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Seeds	MODO	7.66	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	**CLRA**	**11.24**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Carnivore	BLVU	14.5	6.0	30.0	Bravo and Colina, 2005	Adult	Not Specified
Omnivore	**CLRA**	**14.57**	**---**	**---**	**This study**	**Adult**	**Not Specified**

Table H.5: Whole blood lead values in parts per million (ppm) w/w for select avian species and clapper rails in this study. Values are written as they appear in the literature, and values from this study are in boldface

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Herbivore	CANV	---	0.059	0.064	Eisler, 1981	Adult	Not Specified
Herbivore	CANV	---	0.059	0.064	Eisler, 2000	Adult	Reference Site
Seeds	MALL	---	0.0	0.5	Binkowski and Meissner, 2013	Adult	Contaminated Site
Seeds	MALL	---	0.05	0.33	Binkowski and Meissner, 2013	Adult	Reference Site
Seeds	MALL	---	---	10.2	Eisler, 2000	Adult	Contaminated Site
Seeds	MALL	---	0.2	0.5	Eisler, 2000	Adult	Contaminated Site
Carnivore	MAHA	---	0.05	0.11	Eisler, 2000	Adult	Reference Site
Carnivore	MAHA	---	0.35	0.8	Eisler, 2000	Adult	Not Specified
Seeds	ROPI	---	0.0	1.2	Bannon et al. 2011	Adult	Not Specified
Herbivore	TRUS	---	---	0.71	Eisler, 2000	Adult	Not Specified
Herbivore	TUSW	---	1.3	9.6	Eisler, 2000	Adult	Contaminated Site
Herbivore	TUSW	---	0.5	2.3	Eisler, 2000	Adult	Reference Site
Omnivore	WATERFOWL	---	---	>0.2	Eisler, 1988	Adult	Biological Effects-Considered elevated
Carnivore	GOEA	---	---	>0.6	Eisler, 2000	Adult	Biological Effects-Toxic levels
Herbivore	CANV	---	0.059	0.064	Eisler, 2010	Adult	Not Specified
Herbivore	CANV	---	---	0.263	Eisler, 2010	Adult	Not Specified
Herbivore	CANV	---	---	>0.2	Eisler, 2010	Adult	Not Specified
Carnivore	MAHA	---	---	>0.3	Eisler, 2000	Adult	Biological Effects-Elevated levels
Carnivore	GOEA	---	---	>0.2	Eisler, 2000	Adult	Biological Effects-Greater than background levels
Carnivore	MAHA	---	---	>0.6	Eisler, 2000	Adult	Biological Effects-Poisoning levels
Seeds	MALL	---	0.2	0.5	Eisler, 2010	Adult	Biological Effects-Elevated levels
Seeds	MALL	---	---	>0.5	Eisler, 2010	Adult	Biological Effects-Toxic levels

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Seeds	MALL	---	<0.2	---	Eisler, 2010	Adult	Biological Effects-Background levels
Carnivore	FALCONIFORMES	---	0.2	1.5	Friend and Franson, 1999	Adult	Biological Effects-Subclinical signs
Carnivore	FALCONIFORMES	---	---	>1	Friend and Franson, 1999	Adult	Biological Effects-Toxic levels
Carnivore	FALCONIFORMES	---	---	>5	Friend and Franson, 1999	Adult	Biological Effects-Compatible with death
Seeds	COLUMBIFORMES	---	0.2	2.5	Friend and Franson, 1999	Adult	Biological Effects-Subclinical signs
Seeds	COLUMBIFORMES	---	---	>2	Friend and Franson, 1999	Adult	Biological Effects-Toxic levels
Seeds	COLUMBIFORMES	---	---	>10	Friend and Franson, 1999	Adult	Biological Effects-Compatible with death
Not Specified	GALLIFORMES	---	0.2	3	Friend and Franson, 1999	Adult	Biological Effects-Subclinical signs
Not Specified	GALLIFORMES	---	---	>5	Friend and Franson, 1999	Adult	Biological Effects-Toxic levels
Not Specified	GALLIFORMES	---	---	>10	Friend and Franson, 1999	Adult	Biological Effects-Compatible with death
Omnivore	SACR	---	1.46	3.78	Friend and Franson, 1999	Adult	Biological Effects-Exhibited signs of lead toxicosis
Herbivore	GROUSE	---	0.0	1.8	Friend and Franson, 1999	Adult	Biological Effects-Subclinical signs
Herbivore	GROUSE	---	2.0	10.0	Friend and Franson, 1999	Adult	Biological Effects-Toxic levels
Herbivore	GROUSE	---	10.0	26.0	Friend and Franson, 1999	Adult	Biological Effects-Fatal effects
Carnivore	GOEA	---	---	>0.2	Eisler, 2000	Adult	Biological Effects-Elevated levels

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Carnivore	RAPTOR	---	0.0	0.5	Friend and Franson, 1999	Adult	Biological Effects-Subclinical signs
Not Specified	BIRD	---	0.2	0.5	Merck Veterinary Online Manual	Adult	Biological Effects-Within this range is diagnostic for lead toxicosis
Carnivore	RAPTOR	---	0.6	5.0	Friend and Franson, 1999	Adult	Biological Effects-Toxic levels
Carnivore	RAPTOR	---	6.0	26.0	Friend and Franson, 1999	Adult	Biological Effects-Fatal effects
Seeds	PIGEON/DOVE	---	0.0	1.0	Friend and Franson, 1999	Adult	Biological Effects-Subclinical signs
Seeds	PIGEON/DOVE	---	1.0	11.0	Friend and Franson, 1999	Adult	Biological Effects-Toxic levels
Seeds	PIGEON/DOVE	---	11.0	26.0	Friend and Franson, 1999	Adult	Biological Effects-Fatal effects
Omnivore	WATERFOWL	---	---	0.5	Friend and Franson, 1999	Adult	Biological Effects-Toxic levels
Omnivore	WATERFOWL	---	1.0	26.0	Friend and Franson, 1999	Adult	Biological Effects-Fatal effects
Seeds	MALL	---	4	20	Pain, 1996	Adult	Biological Effects-Died of lead poisoning
Herbivore	MUSW	---	0.19	4.30	Day et al., 2003	Adult	Biological Effects-Diet with lead
Seeds	MALL	---	5	18	Pain, 1996	Adult	Biological Effects-Died of lead poisoning
Seeds	MALL	---	3	18	Pain, 1996	Adult	Biological Effects-Died of lead poisoning
Insects	AMRO	---	---	0.87	Eisler, 2000	Nestling/chick	Not Specified
Fish	OSPR	---	<2	0.024	Langner et al., 2012	Nestling/chick	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	BAEA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	BRPE	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	DCCO	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	BMDL	---	---	CEE-TV	Adult	Not Specified
Herbivore	MUSW	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	BMDL	---	---	CEE-TV	Adult	Not Specified
Omnivore	RBGU	BMDL	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	BMDL	---	---	CEE-TV	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**0.00**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Not Specified
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Not Specified
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Not Specified
Seeds	ATSP	0.0004	---	---	Brumbaugh, 2006	Adult	Reference Site
Seeds	CORE	0.0024	---	---	Brumbaugh, 2006	Adult	Reference Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Not Specified	NOT SPECIFIED	0.0028	---	---	Brumbaugh, 2006	Adult	Reference Site
Aquatic Inverts	REPH	0.004	ND	0.006	Hargreaves et al., 2011	Adult	Not Specified
Seeds	CORE	0.0057	---	---	Brumbaugh, 2006	Adult	Reference Site
Fish	SPOONBILL	0.008	0.002	0.034	Benito et al., 1999	Adult	Not Specified
Fish	LAAL	0.0085	---	---	CEE-TV	Adult	Not Specified
Fish	WOST	0.00889	0.00347	0.0312	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Seeds	CORE	0.009	---	---	Brumbaugh, 2006	Adult	Contaminated Site
Insects	PIFL	0.01	---	---	Berglund and Nyholm, 2011	Adult	Reference Site
Insects	PIFL	0.01	---	---	Berglund and Nyholm, 2011	Adult	Reference Site
Aquatic Inverts	RUTU	0.01	ND	0.039	Hargreaves et al., 2011	Adult	Not Specified
Carnivore	MAHA	0.01	---	---	Eisler, 2000	Juv/sub adult	Not Specified
Omnivore	FRGU	0.012	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	BFAL	0.013	0.0051	0.026	Finkelstein et al., 2007	Adult	Not Specified
Omnivore	NOMO	0.013	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Omnivore	NOMO	0.013	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	ATFL	0.0136	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Aquatic Inverts	BLSC	0.014	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	STEI	0.014	---	---	CEE-TV	Adult	Not Specified
Insects	ATFL	0.014	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	SPPL	0.014	0.006	0.05	Hargreaves et al., 2011	Adult	Not Specified
Fish	GRAY HERON	0.015	0.002	0.089	Benito et al., 1999	Adult	Not Specified
Seeds	BHCO	0.016	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site
Seeds	BHCO	0.016	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	DUNL	0.018	0.014	0.021	Hargreaves et al., 2011	Adult	Not Specified
Seeds	BHCO	0.019	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	BHCO	0.019	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	WRSA	0.019	0.004	0.074	Hargreaves et al., 2011	Adult	Not Specified
Fish	GCGR	0.02	---	---	Benito et al., 1999	Adult	Not Specified
Aquatic Inverts	KIEI	0.02	0.006	0.09	Wayland et al., 2008	Adult	Not Specified
Omnivore	YLGU	0.02	0.009	0.032	Benito et al., 1999	Adult	Not Specified
Fish	OSPR	0.02	---	---	Eisler, 2000	Nestling/chick	Reference Site
Seeds	HOSP	0.021	---	---	Chandler et al., 2004	Adult	Reference Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Seeds	HOSP	0.021	---	---	Chandler et al., 2004	Adult	Reference Site
Insects	BCFL	0.0217	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	NOCA	0.0238	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	NOCA	0.0238	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Carnivore	NOGO	0.025	---	---	Stout et al., 2010	Adult	Not Specified
Insects	SOSP	0.027	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	HOOR	0.0274	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	SAVS	0.0288	---	---	Brumbaugh, 2006	Adult	Contaminated Site
Omnivore	FRGU	0.029	---	---	CEE-TV	Adult	Not Specified
Insects	CAKI	0.029	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	GFWO	0.0291	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	GFWO	0.0291	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	PIFL	0.03	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Omnivore	**CLRA**	**0.03**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**0.03**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**0.03**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**0.03**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	SAPH	0.0303	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	SAPH	0.0303	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	SOSP	0.031	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	SOSP	0.031	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	YBCH	0.032	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	CRTH	0.0328	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	CRTH	0.0328	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	DMSA	0.0362	0.0145	0.0689	Summers et al., 2014	Adult	Not Specified
Insects	ATFL	0.0386	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site
Insects	ATFL	0.0386	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	SOSP	0.039	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	ATFL	0.0393	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	ATFL	0.0393	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	SAVS	0.0399	---	---	Brumbaugh, 2006	Adult	Contaminated Site
Fish	OSPR	0.04	---	---	Eisler, 2000	Adult	Reference Site
Insects	PIFL	0.04	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.04	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Seeds	PYRR	0.0402	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	PYRR	0.0402	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	SOSP	0.041	---	---	Lester and Riper, 2014	Adult	Reference Site
Insects	CBTH	0.0435	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	CBTH	0.0435	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	CACW	0.0446	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	LAAL	0.0450	---	---	CEE-TV	Adult	Reference Site
Insects	CAKI	0.045	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site
Insects	CAKI	0.045	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	BAEA	0.046	---	---	CEE-TV	Adult	Not Specified
Seeds	CANT	0.046	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	CANT	0.046	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	KING PENGUIN	0.0464	0.008	0.1307	Summers et al., 2014	Adult	Not Specified
Insects	CACW	0.0466	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	BCFL	0.0468	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site
Insects	BCFL	0.0468	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	SAVS	0.0474	---	---	Brumbaugh, 2006	Adult	Contaminated Site
Insects	LBWO	0.048	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	ROCK DOVE	0.05	---	---	Eisler, 2000	Adult	Reference Site
Fish	LMSA	0.0512	0.0433	0.0553	Summers et al., 2014	Adult	Not Specified
Insects	SAVS	0.0524	---	---	Brumbaugh, 2006	Adult	Contaminated Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	MACARONI PENGUIN	0.0527	0.0295	0.0706	Summers et al., 2014	Adult	Not Specified
Carnivore	BLKI	0.054	0.002	0.179	Benito et al., 1999	Adult	Not Specified
Insects	BLGR	0.0558	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Not Specified	NOT SPECIFIED	0.0587	---	---	Brumbaugh, 2006	Adult	Contaminated Site
Insects	PIFL	0.06	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Omnivore	PUGA	0.06	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.06**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Fish	CROZET SHAG	0.0601	0.0137	0.1075	Summers et al., 2014	Adult	Not Specified
Insects	GLIB	0.061	0.02	0.233	Benito et al., 1999	Adult	Not Specified
Fish	BAEA	0.063	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.063	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	0.066	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.067	---	---	CEE-TV	Adult	Not Specified
Fish	WHST	0.071	0.002	0.32	Benito et al., 1999	Adult	Not Specified
Omnivore	NOMO	0.071	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Aquatic Inverts	POCH	0.073	0.025	0.274	Benito et al., 1999	Adult	Not Specified
Fish	BAEA	0.074	---	---	CEE-TV	Adult	Not Specified
Seeds	ATSP	0.0744	---	---	Brumbaugh, 2006	Adult	Contaminated Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	GRFL	0.076	0.035	0.12	Benito et al., 1999	Adult	Not Specified
Seeds	CANT	0.0761	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site
Seeds	CANT	0.0761	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	YBCH	0.0765	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	BAEA	0.077	---	---	CEE-TV	Adult	Not Specified
Carnivore	GOEA	0.08	---	0.19	Eisler, 2000	Adult	Not Specified
Seeds	HOSP	0.083	---	---	Chandler et al., 2004	Adult	Contaminated Site
Fish	NOGA	0.083	---	---	CEE-TV	Adult	Not Specified
Fish	SGPE	0.0848	0.0725	0.0971	Summers et al., 2014	Adult	Not Specified
Fish	COLO	0.085	---	---	CEE-TV	Adult	Not Specified
Insects	SAVS	0.0852	---	---	Brumbaugh, 2006	Adult	Contaminated Site
Insects	YBCH	0.086	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	YBCH	0.086	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	NOCA	0.087	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	ATFL	0.087	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	CANT	0.0872	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	ROCKHOPPER PENGUIN	0.0881	0.071	0.1123	Summers et al., 2014	Adult	Not Specified
Fish	BAEA	0.09	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	0.09	---	---	Eisler, 2000	Nestling/chick	Contaminated Site

Diet	**AOU Code**	**Mean**	**Low Range**	**High Range**	**Reference Source**	**Age**	**Site Status**
Insects	BLGR	0.091	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	BLGR	0.091	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Omnivore	HEGU	0.094	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	GFWO	0.0948	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	HOSP	0.095	---	---	Chandler et al., 2004	Adult	Contaminated Site
Insects	BCFL	0.0951	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	WAAL	0.0965	0.0346	0.2216	Summers et al., 2014	Adult	Not Specified
Seeds	MALL	0.1	---	---	Eisler, 2000	Adult	Biological Effects-Background levels
Aquatic Inverts	ABDU	0.1	---	---	Eisler, 2000	Adult	Not Specified
Aquatic Inverts	KIEI	0.1	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.10**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**0.10**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	LBWO	0.104	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	BEWR	0.106	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site
Insects	BEWR	0.106	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Omnivore	CASJ	0.107	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	WOST	0.1071	0.0278	0.7805	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Seeds	HOSP	0.108	---	---	Chandler et al., 2004	Adult	Contaminated Site
Insects	SOSP	0.108	---	---	Lester and Riper, 2014	Adult	Contaminated Site
Herbivore	MUSW	0.11	0.07	0.39	Eisler, 2000	Adult	Not Specified
Aquatic Inverts	KIEI	0.11	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.114	---	---	CEE-TV	Adult	Not Specified
Insects	LBWO	0.1163	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	NGPE	0.1181	0.0944	0.1322	Summers et al., 2014	Adult	Not Specified
Herbivore	GADW	0.12	0.069	0.174	Benito et al., 1999	Adult	Not Specified
Aquatic Inverts	SPEI	0.12	---	---	CEE-TV	Adult	Not Specified
Insects	CRTH	0.121	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Aquatic Inverts	SPEI	0.13	---	---	CEE-TV	Adult	Not Specified
Seeds	ATSP	0.132	---	---	Brumbaugh, 2006	Adult	Contaminated Site
Seeds	WWDO	0.133	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Aquatic Inverts	COEI	0.14	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	SPEI	0.14	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	**CLRA**	**0.14**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Aquatic Inverts	SPEI	0.14	---	---	CEE-TV	Nestling/chick	Not Specified
Seeds	BHCO	0.1427	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	WOST	0.1464	0.0537	0.5027	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Carnivore	COMMON BUZZARD	0.1471	ND	6.31473	Carneiro et al., 2014	Adult	Not Specified
Carnivore	MAHA	0.15	---	---	Eisler, 2000	Adult	Not Specified
Omnivore	**CLRA**	**0.15**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Insects	BUOR	0.1505	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	CBTH	0.151	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	WWDO	0.153	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	WWDO	0.153	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	WWDO	0.16	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	CANT	0.173	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	BCFL	0.1735	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	HOSP	0.174	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site
Seeds	HOSP	0.174	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Omnivore	HEGU	0.176	---	---	CEE-TV	Juv/sub adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	CACW	0.1776	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	CAGO	0.18	---	---	Eisler, 2000	Adult	Not Specified
Insects	YBCH	0.1808	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	CBTH	0.1824	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	BAEA	0.188	---	---	CEE-TV	Juv/sub adult	Not Specified
Herbivore	MUSW	0.19	0.17	0.19	Day et al., 2003	Adult	Biological Effects-Control Diet
Carnivore	GOEA	0.19	---	1.3	Eisler, 2000	Juv/sub adult	Not Specified
Herbivore	CANV	0.2	---	---	Eisler, 2000	Adult	Not Specified
Fish	LAAL	0.2	---	26.7	Eisler, 2000	Adult	Not Specified
Fish	OSPR	0.2	---	---	Eisler, 2000	Adult	Contaminated Site
Aquatic Inverts	ABDU	0.2	---	---	Eisler, 2000	Adult	Not Specified
Aquatic Inverts	ABDU	0.2	---	---	Eisler, 2000	Adult	Not Specified
Aquatic Inverts	BLSC	0.20	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	STEI	0.20	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	ABDU	0.2	---	---	Eisler, 2000	Juv/sub adult	Not Specified
Fish	BAEA	0.203	---	---	CEE-TV	Adult	Not Specified
Seeds	MALL	0.208	0.045	0.454	Benito et al., 1999	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Herbivore	MUSW	0.21	0.001	1.28	Eisler, 2000	Adult	Not Specified
Insects	PIFL	0.21	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Omnivore	NOMO	0.212	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	CANT	0.215	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	CBTH	0.216	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Aquatic Inverts	LESC	0.22	---	---	Eisler, 2000	Adult	Not Specified
Omnivore	CASJ	0.225	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site
Omnivore	CASJ	0.225	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	PIFL	0.23	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Seeds	MODO	0.23	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Omnivore	HEGU	0.233	---	---	CEE-TV	Adult	Not Specified
Seeds	INDO	0.234	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Seeds	PYRR	0.238	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	BAEA	0.245	---	---	CEE-TV	Juv/sub adult	Not Specified
Herbivore	MUSW	0.25	0.13	0.54	Eisler, 2000	Adult	Not Specified
Herbivore	CANV	0.263	---	---	Eisler, 2000	Adult	Not Specified
Fish	BAEA	0.266	---	---	CEE-TV	Juv/sub adult	Not Specified
Carnivore	GOEA	0.28	---	4.1	Eisler, 2000	Juv/sub adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Aquatic Inverts	LESC	0.29	---	---	CEE-TV	Adult	Not Specified
Insects	CACW	0.3022	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Herbivore	CANV	0.31	---	---	Eisler, 2000	Adult	Not Specified
Insects	PIFL	0.31	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Omnivore	**CLRA**	**0.33**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Seeds	HOSP	0.381	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Insects	RNSA	0.389	---	---	Chapa-Vargas et al., 2010	Adult	Reference Site
Insects	RNSA	0.389	---	---	Chapa-Vargas et al., 2010	Adult	Contaminated Site
Fish	BAEA	0.394	---	---	CEE-TV	Adult	Not Specified
Carnivore	GOEA	0.4	---	5.5	Eisler, 2000	Adult	Not Specified
Seeds	MALL	0.4	---	---	Eisler, 2000	Adult	Not Specified
Insects	RWBL	0.419			Tsipoura et al., 2008	Adult	Not Specified
Fish	BAEA	0.46	---	---	CEE-TV	Adult	Biological Effects-Died of lead poisoning
Fish	LAAL	0.4800	---	---	CEE-TV	Nestling/chick	Contaminated Site
Insects	PIFL	0.49	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Seeds	MALL	0.5	---	---	Eisler, 2000	Adult	Contaminated Site
Omnivore	**CLRA**	**0.50**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Herbivore	MUSW	0.52	---	---	Eisler, 2000	Adult	Biological Effects-Died of lead poisoning

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Aquatic Inverts	SPEI	0.54	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.546	---	---	CEE-TV	Adult	Not Specified
Herbivore	RNDU	0.55	---	---	Eisler, 2000	Adult	Not Specified
Aquatic Inverts	STEI	0.59	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	WODU	0.6	---	---	Eisler, 2000	Adult	Reference Site
Aquatic Inverts	SPEI	0.64	---	---	CEE-TV	Nestling/chick	Not Specified
Aquatic Inverts	SPEI	0.74	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.76**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Herbivore	MUSW	0.79	0.004	9.62	Eisler, 2000	Adult	Not Specified
Insects	MAWR	0.796			Tsipoura et al., 2008	Adult	Not Specified
Fish	BAEA	0.8	---	---	Eisler, 2000	Adult	Not Specified
Carnivore	CACO	0.802	---	---	CEE-TV	Adult	Biological Effects-Observed eating lead-shot carcass
Fish	BAEA	0.871	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	0.924	---	---	CEE-TV	Adult	Not Specified
Insects	TRSW	0.944			Tsipoura et al., 2008	Adult	Not Specified
Carnivore	CACO	0.944	---	---	CEE-TV	Adult	Biological Effects-Had lead poisoning
Fish	BAEA	0.967	---	---	CEE-TV	Adult	Not Specified
Seeds	ROCK DOVE	1	0.3	17	Eisler, 2000	Adult	Contaminated Site
Omnivore	**CLRA**	**1.04**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Carnivore	RTHA	1.65	---	---	CEE-TV	Adult	Biological Effects-Diagnosed with lead toxicity
Herbivore	TRUS	1.7	---	---	CEE-TV	Adult	Biological Effects-Lead shot found in gut
Carnivore	CACO	1.8	---	---	Eisler, 2000	Juv/sub adult	Biological Effects-Found dead of lead poisoning
Aquatic Inverts	SPEI	2.02	---	---	CEE-TV	Adult	Not Specified
Herbivore	TRUS	2.4	---	---	Eisler, 2000	Adult	Biological Effects-Died of lead poisoning
Fish	COLO	3.03	---	---	CEE-TV	Adult	Not Specified
Fish	LAAL	3.7	---	---	CEE-TV	Nestling/chick	Biological Effects-Signs of lead poisoning
Omnivore	WHCR	5.6	---	---	Friend and Franson, 1999	Adult	Not Specified
Omnivore	WHCR	5.7	---	---	Eisler, 2000	Juv/sub adult	Biological Effects-Died of lead poisoning
Carnivore	BLVU*	6.85	0.3	15.0	Bravo and Colina, 2005	Adult	Not Specified
Aquatic Inverts	WODU	8	---	---	Eisler, 2000	Adult	Contaminated Site
Omnivore	**CLRA**	**8.02**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Aquatic Inverts	SPEI	8.5	---	---	Eisler, 2000	Adult	Not Specified
Fish	BAEA	12.5	---	---	CEE-TV	Adult	Not Specified
Carnivore	CACO	14.5	---	---	CEE-TV	Adult	Contaminated Site
Carnivore	CACO	15.4	---	---	CEE-TV	Adult	Contaminated Site
Aquatic Inverts	SPEI	81.5	---	---	Eisler, 2000	Adult	Biological Effects-Found dead or moribund
Fish	COLO	16.1	---	---	CEE-TV	Adult	Not Specified

Table H.6: Whole blood mercury values in parts per million (ppm) w/w for select avian species and clapper rails in this study. Values are written as they appear in the literature, and values from this study are in boldface

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	BCCH	---	0.120	0.150	Jackson et al., 2015	Adult	Not Specified
Insects	CACH	---	0.060	0.200	Jackson et al., 2015	Adult	Not Specified
Insects	CARW	---	0.090	0.400	Jackson et al., 2015	Adult	Not Specified
Fish	COLO	---	---	5.62	Meyer et al., 1995	Adult	Not Specified
Insects	COYE	---	0.070	0.600	Jackson et al., 2015	Adult	Not Specified
Insects	EABL	---	0.050	0.300	Jackson et al., 2015	Adult	Not Specified
Fish	GREG	---	0.1	4	Sepulveda et al.,1999	Adult	Not Specified
Insects	GRCA	---	0.050	0.300	Jackson et al., 2015	Adult	Not Specified
Insects	HETH	---	0.020	0.400	Jackson et al., 2015	Adult	Not Specified
Insects	HETH	---	0.700	0.800	Jackson et al., 2015	Adult	Not Specified
Insects	HOWR	---	0.080	0.200	Jackson et al., 2015	Adult	Not Specified
Insects	INBU	---	0.005	0.090	Jackson et al., 2015	Adult	Not Specified
Insects	LISP	---	0.010	0.850	Jackson et al., 2015	Adult	Not Specified
Insects	NAWA	---	0.050	0.300	Jackson et al., 2015	Adult	Not Specified
Insects	NESP	---	0.2	1	McKay and Maher, 2012	Adult	Not Specified
Seeds	NOCA	---	0.010	0.120	Jackson et al., 2015	Adult	Not Specified
Insects	OVEN	---	0.020	0.110	Jackson et al., 2015	Adult	Not Specified
Insects	PAWA	---	0.150	0.900	Jackson et al., 2015	Adult	Not Specified
Insects	PIFL	---	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	---	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	REVI	---	0.050	0.700	Jackson et al., 2015	Adult	Not Specified
Insects	REVI	---	0.050	0.200	Jackson et al., 2015	Adult	Not Specified
Insects	REVI	---	0.700	0.750	Jackson et al., 2015	Adult	Not Specified
Insects	RUBL	---	0.200	0.900	Jackson et al., 2015	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	RWBL	---	0.1	5.2	CEE-TV	Adult	Contaminated Site
Insects	RWBL	---	0.080	0.800	Jackson et al., 2015	Adult	Not Specified
Fish	SNEG	---	1.5	4.8	Hoffman et al., 2009	Adult	Not Specified
Insects	SOSP	---	0.1	1.3	CEE-TV	Adult	Contaminated Site
Insects	SOSP	---	0.040	0.500	Jackson et al., 2015	Adult	Not Specified
Insects	SOSP	---	0.050	0.600	Jackson et al., 2015	Adult	Not Specified
Insects	SWSP	---	0.750	0.750	Jackson et al., 2015	Adult	Not Specified
Insects	SWTH	---	0.050	0.200	Jackson et al., 2015	Adult	Not Specified
Insects	TRSW	---	0.600	0.800	Jackson et al., 2015	Adult	Not Specified
Insects	TRSW	---	0.050	0.400	Jackson et al., 2015	Adult	Not Specified
Insects	TRSW	---	0.060	0.900	Jackson et al., 2015	Adult	Not Specified
Insects	TRFL	---	0.200	0.250	Jackson et al., 2015	Adult	Not Specified
Insects	TRSW	---	0.1	0.6	CEE-TV	Adult	Contaminated Site
Seeds	WTSP	---	0.010	0.120	Jackson et al., 2015	Adult	Not Specified
Insects	YEWA	---	0.009	0.100	Jackson et al., 2015	Adult	Not Specified
Seeds	MALL	---	0.5	4.2	Heinz, et al., 2010	Adult	Biological Effects-Fed varying levels of mercury in diet
Insects	EUST	---	3.5	14	Carlson et al., 2014	Juv/sub adult	Biological Effects-Fed mercury in diet 1.5 ppm
Insects	EUST	---	1.5	7.5	Carlson et al., 2014	Juv/sub adult	Biological Effects-Fed mercury in diet 0.75 ppm
Fish	FOTE	---	0.1	6.00	Ackerman et al., 2011	Nestling/chick	Contaminated Site
Aquatic Inverts	AMAV	---	0.02	2.00	Ackerman et al., 2011	Nestling/chick	Contaminated Site
Aquatic Inverts	BNST	---	0.03	3.00	Ackerman et al., 2011	Nestling/chick	Contaminated Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	OSPR	---	0.097	2.786	Langner et al., 2012	Nestling/chick	Not Specified
Not Specified	BIRD	---	---	>6	Merck Veterinary Online Manual	Not Specified	Not Specified
Not Specified	BIRD	---	<0.1	---	Merck Veterinary Online Manual	Not Specified	Not Specified
Not Specified	BIRD	---	9	---	Winder, 2012	Not Specified	Biological Effects-Low Risk
Not Specified	BIRD	---	0.7	2.9	Winder, 2012	Not Specified	Biological Effects-Moderate Risk
Not Specified	BIRD	---	---	>2.9	Winder, 2012	Not Specified	Biological Effects-High Risk
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	GBHE	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Herbivore	MUSW	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	OSPR	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Omnivore	RBGU	Below minimum detection limit	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.00**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	ACFL	0.0067	-0.0048	0.0182	Rowse et al., 2014	Nestling/chick	Not Specified
Seeds	AMGO	0.01	---	---	CEE-TV	Adult	Not Specified
Insects	ACFL	0.0132	-0.0052	0.0316	Rowse et al., 2014	Nestling/chick	Not Specified
Fish	BAEA	0.0149	---	---	CEE-TV	Adult	Not Specified
Insects	TRSW	0.01732	---	---	CEE-TV	Nestling/chick	Contaminated Site
Insects	TRSW	0.0194			Tsipoura et al., 2008	Adult	Not Specified
Insects	BOBO	0.02	---	---	CEE-TV	Adult	Not Specified
Insects	INBU	0.02	0.0	0.0	Jackson et al., 2011	Adult	Not Specified
Insects	INBU	0.02	0.0	0.0	Jackson et al., 2011	Adult	Reference Site
Seeds	MALL	0.02	---	---	CEE-TV	Adult	Not Specified
Insects	TRSW	0.02	---	---	CEE-TV	Nestling/chick	Not Specified
Omnivore	FRGU	0.021	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	ACFL	0.021	---	---	Rowse et al., 2014	Nestling/chick	Not Specified
Fish	BAEA	0.0223	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	RWBL	0.0232			Tsipoura et al., 2008	Adult	Not Specified
Fish	WOST	0.02436	0.00624	0.0621	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Insects	ACFL	0.0253	0.02224	0.02836	Rowse et al., 2014	Nestling/chick	Not Specified
Insects	ACFL	0.0253	0.02322	0.02738	Rowse et al., 2014	Nestling/chick	Not Specified
Fish	BAEA	0.0255	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.026	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.028	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.0287	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.03	---	---	CEE-TV	Adult	Not Specified
Insects	PIFL	0.03	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	0.03	---	---	Berglund and Nyholm, 2011	Adult	Reference Site
Fish	BAEA	0.0302	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.0303	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.031	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.032	---	---	CEE-TV	Adult	Not Specified
Insects	ACFL	0.0325	0.0261	0.0389	Rowse et al., 2014	Nestling/chick	Not Specified
Fish	BAEA	0.033	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.0332	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.035	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	0.035	---	---	Lester and Riper, 2014	Adult	Contaminated Site
Insects	MAWR	0.0353			Tsipoura et al., 2008	Adult	Not Specified
Fish	BAEA	0.0363	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.0369	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	BAEA	0.039	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.039	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.04	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.04**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Fish	BAEA	0.041	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.041	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.041	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.041	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.042	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.044	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.044	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.045	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.046	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.046	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	0.046	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	AMRO	0.05	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.05	---	---	CEE-TV	Adult	Not Specified
Insects	BOBO	0.05	---	---	CEE-TV	Adult	Not Specified
Insects	COYE	0.05	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	0.05	0.0	0.1	Jackson et al., 2011	Adult	Not Specified
Insects	SOSP	0.05	0.0	0.1	Jackson et al., 2011	Adult	Reference Site
Fish	WOST	0.05303	0.016	0.1183	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Fish	BAEA	0.054	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.055	---	---	CEE-TV	Adult	Not Specified
Insects	BPWA	0.055	---	---	CEE-TV	Adult	Not Specified

Diet	**AOU Code**	**Mean**	**Low Range**	**High Range**	**Reference Source**	**Age**	**Site Status**
Omnivore	FRGU	0.056	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	0.058	---	---	Lester and Riper, 2014	Adult	Reference Site
Seeds	NOCA	0.06	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.06**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Fish	BAEA	0.061	---	---	CEE-TV	Adult	Not Specified
Seeds	WTSP	0.062	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.064	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	0.065	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	INBU	0.07	0.0	0.2	Jackson et al., 2011	Adult	Not Specified
Insects	INBU	0.07	0.0	0.2	Jackson et al., 2011	Adult	Contaminated Site
Insects	PIFL	0.07	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Aquatic Inverts	SPEI	0.07	---	---	CEE-TV	Nestling/chick	Not Specified
Omnivore	HEGU	0.071	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	SOSP	0.072	---	---	Lester and Riper, 2014	Adult	Not Specified
Fish	BCNH	0.0759	---	---	CEE-TV	Nestling/chick	Reference Site
Insects	INBU	0.08	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	LESC	0.08	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	0.080	---	---	Lester and Riper, 2014	Adult	Not Specified
Fish	BCNH	0.080	---	---	CEE-TV	Nestling/chick	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	WOST	0.08267	0.0432	0.1818	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Fish	BAEA	0.085	---	---	CEE-TV	Nestling/chick	Not Specified
Insects	ACFL	0.087	---	---	Rowse et al., 2014	Adult	Not Specified
Insects	BITH	0.09	---	---	CEE-TV	Adult	Not Specified
Insects	RBWO	0.09	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.09**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	EABL	0.09	---	---	CEE-TV	Nestling/chick	Not Specified
Insects	YRWA	0.091	---	---	CEE-TV	Adult	Not Specified
Omnivore	HEGU	0.093	---	---	CEE-TV	Adult	Not Specified
Omnivore	HEGU	0.095	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	ACFL	0.097	---	---	Rowse et al., 2014	Adult	Not Specified
Insects	GRCA	0.1	---	---	CEE-TV	Adult	Not Specified
Fish	RTLO	0.10	---	---	CEE-TV	Adult	Not Specified
Insects	ACFL	0.106	---	---	Rowse et al., 2014	Adult	Not Specified
Insects	SOSP	0.11	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.11**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	ACFL	0.115	---	---	Rowse et al., 2014	Adult	Not Specified
Fish	BAEA	0.115	---	---	CEE-TV	Nestling/chick	Not Specified
Insects	EABL	0.12	---	---	CEE-TV	Adult	Not Specified
Insects	EAPH	0.12	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	SPEI	0.12	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	SOSP	0.12	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.12**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**0.13**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Fish	BCNH	0.138	---	---	CEE-TV	Nestling/chick	Not Specified
Insects	HOWR	0.14	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	SPEI	0.14	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	SPEI	0.14	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	SPEI	0.14	---	---	CEE-TV	Adult	Not Specified
Insects	BARS	0.14	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	COLO	0.14	0.04	0.6	Eisler, 2000	Nestling/chick	Not Specified
Aquatic Inverts	COEI	0.15	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	LESA	0.15	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	SPEI	0.15	---	---	CEE-TV	Adult	Not Specified
Insects	TUTI	0.15	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.15	---	---	CEE-TV	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**0.15**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	**CLRA**	**0.15**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Aquatic Inverts	SPEI	0.15	---	---	CEE-TV	Nestling/chick	Not Specified
Insects	INBU	0.16	0.1	0.4	Jackson et al., 2011	Adult	Not Specified
Insects	INBU	0.16	0.1	0.4	Jackson et al., 2011	Adult	Contaminated Site
Insects	TRSW	0.16	0.12	0.2	Lane et al., 2011	Adult	Not Specified
Insects	TRSW	0.16	---	---	CEE-TV	Adult	Contaminated Site
Insects	TRSW	0.16	---	---	CEE-TV	Adult	Contaminated Site
Fish	COLO	0.16	0.03	0.78	Eisler, 2000	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**0.16**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Fish	BAEA	0.169	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	KIEI	0.17	0.06	0.33	Wayland et al., 2008	Adult	Not Specified
Insects	TRSW	0.17	---	---	CEE-TV	Adult	Not Specified
Insects	TRSW	0.17	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	0.18	---	---	CEE-TV	Adult	Not Specified
Carnivore	EASO	0.18	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	0.18	---	---	Kenow et al., 2007	Nestling/chick	
Insects	CARW	0.19	0.05	0.2	Schulwitz et al., 2015	Nestling/chick	Not Specified
Insects	ACFL	0.191	---	---	Rowse et al., 2014	Adult	Not Specified
Insects	DUNL	0.193	0.13	0.23	Hargreaves et al., 2011	Adult	Not Specified
Aquatic Inverts	SPEI	0.2	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	EABL	0.20	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	BAEA	0.2	0.02	0.6	Eisler, 2000	Nestling/chick	Not Specified
Carnivore	COMMON BUZZARD	0.2094	Not detected	1.64895	Carneiro et al., 2014	Adult	Not Specified
Aquatic Inverts	LESA	0.21	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	SALS	0.21	---	---	CEE-TV	Juv/sub adult	Not Specified
Omnivore	**CLRA**	**0.21**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Aquatic Inverts	SPEI	0.22	---	---	CEE-TV	Adult	Not Specified
Insects	CACH	0.23	---	---	CEE-TV	Adult	Not Specified
Fish	RTLO	0.23	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.23	---	---	CEE-TV	Adult	Not Specified
Insects	TRSW	0.23	---	---	CEE-TV	Nestling/chick	Not Specified
Insects	SPPL	0.235	0.063	0.37	Hargreaves et al., 2011	Adult	Not Specified
Insects	MAWR	0.24	---	---	CEE-TV	Adult	Not Specified
Insects	REVI	0.24	0.2	0.3	Jackson et al., 2011	Adult	Not Specified
Insects	REVI	0.24	0.2	0.3	Jackson et al., 2011	Adult	Reference Site
Insects	TRSW	0.24	0.21	0.27	Lane et al., 2011	Adult	Not Specified
Fish	BEKI	0.25	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	AMAV	0.25	---	---	Ackerman et al., 2007	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Aquatic Inverts	AMAV	0.25	0.0	2.75	Ackerman et al., 2007	Adult	Not Specified
Insects	TRSW	0.25	0.22	0.28	Lane et al., 2011	Adult	Not Specified
Insects	NESP	0.256	---	---	CEE-TV	Adult	Not Specified
Insects	INBU	0.26	0.1	0.5	Jackson et al., 2011	Adult	Not Specified
Insects	INBU	0.26	0.1	0.5	Jackson et al., 2011	Adult	Contaminated Site
Insects	SESP	0.26	---	---	CEE-TV	Adult	Not Specified
Insects	BITH	0.27	---	---	CEE-TV	Adult	Not Specified
Insects	INBU	0.27	0.1	0.6	Jackson et al., 2011	Adult	Not Specified
Insects	INBU	0.27	0.1	0.6	Jackson et al., 2011	Adult	Contaminated Site
Insects	SALS	0.27	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	COLO	0.279	---	---	CEE-TV	Adult	Not Specified
Insects	NESP	0.29	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.29**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Insects	EABL	0.3	0.1	0.6	Schulwitz et al., 2015	Adult	Not Specified
Insects	INBU	0.3	0.1	0.6	Jackson et al., 2011	Adult	Not Specified
Insects	INBU	0.3	0.1	0.6	Jackson et al., 2011	Adult	Contaminated Site
Aquatic Inverts	KIEI	0.30	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.31	---	---	CEE-TV	Adult	Not Specified
Seeds	CHSP	0.31	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	KIEI	0.31	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.31	---	---	CEE-TV	Adult	Not Specified
Insects	SESP	0.31	---	---	Warner et al., 2010	Adult	Not Specified
Fish	GBHE	0.314	---	---	CEE-TV	Adult	Not Specified
Insects	CARW	0.33	0.2	0.7	Jackson et al., 2011	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	CARW	0.33	0.2	0.7	Jackson et al., 2011	Adult	Reference Site
Fish	OSPR	0.33	---	---	CEE-TV	Adult	Not Specified
Fish	FOTE	0.33	---	---	Ackerman et al., 2008	Juv/sub adult	Not Specified
Insects	NESP	0.34	---	---	CEE-TV	Adult	Not Specified
Insects	WRSA	0.347	0.13	0.68	Hargreaves et al., 2011	Adult	Not Specified
Insects	TRSW	0.35	---	---	CEE-TV	Adult	Not Specified
Insects	ACFL	0.351	---	---	Rowse et al., 2014	Adult	Not Specified
Fish	RTLO	0.36	---	---	CEE-TV	Adult	Not Specified
Insects	REVI	0.36	---	---	CEE-TV	Adult	Not Specified
Fish	COTE	0.37	---	---	trace metal concentrations in marine organisms	Adult	Not Specified
Fish	COTE	0.37	---	---	Eisler, 2010	Adult	Not Specified
Fish	BAEA	0.373	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	BBPL	0.378	0.19	0.57	Hargreaves et al., 2011	Adult	Not Specified
Fish	BCNH	0.38	0.23	0.83	Hoffman et al., 2009	Adult	Not Specified
Insects	BITH	0.38	---	---	CEE-TV	Adult	Not Specified
Insects	BLRA	0.38	---	---	Tsao, 2009	Adult	Not Specified
Insects	SESA	0.38	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	LESA	0.39	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	NESP	0.398	---	---	CEE-TV	Adult	Not Specified
Fish	OSPR	0.4	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.4	---	---	Warner et al., 2010	Adult	Not Specified
Fish	OSPR	0.4	---	---	Eisler, 2000	Nestling/chick	Reference Site

Diet	**AOU Code**	**Mean**	**Low Range**	**High Range**	**Reference Source**	**Age**	**Site Status**
Insects	CARW	0.41	---	---	CEE-TV	Adult	Not Specified
Fish	BCNH	0.41	---	---	CEE-TV	Juv/sub adult	Not Specified
Not Specified	SOSP	0.42	0.1	1.0	Jackson et al., 2011	Adult	Not Specified
Insects	SOSP	0.42	0.1	1.0	Jackson et al., 2011	Adult	Contaminated Site
Insects	SALS	0.43	0.35	0.54	Lane et al., 2011	Adult	Not Specified
Insects	SESP	0.43	---	---	Warner et al., 2010	Adult	Not Specified
Insects	SALS	0.44	---	---	Warner et al., 2010	Adult	Not Specified
Insects	SALS	0.44	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	0.445	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	0.446	---	---	CEE-TV	Adult	Not Specified
Insects	CACH	0.45	---	---	CEE-TV	Adult	Not Specified
Insects	MAWR	0.45	0.27	0.77	Hartman et al., 2013	Adult	Not Specified
Insects	NESP	0.45	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.45	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.45	---	---	CEE-TV	Adult	Not Specified
Insects	SESP	0.45	---	---	Warner et al., 2010	Adult	Not Specified
Fish	NOGA	0.454	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.46	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	NESP	0.47	---	---	CEE-TV	Adult	Not Specified
Insects	NESP	0.47	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.47	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.47	---	---	Warner et al., 2010	Adult	Not Specified
Insects	SALS	0.47	---	---	Warner et al., 2010	Adult	Not Specified
Fish	BAEA	0.471	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	0.478	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	**CLRA**	**0.48**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Fish	NOGA	0.482	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	0.494	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.50	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	REPH	0.508	0.095	0.81	Hargreaves et al., 2011	Adult	Not Specified
Insects	NESP	0.51	---	---	CEE-TV	Adult	Not Specified
Fish	RTLO	0.51	---	---	CEE-TV	Adult	Not Specified
Insects	EABL	0.52	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	SALS	0.53	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	0.53	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	SALS	0.54	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.54	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.54	---	---	Warner et al., 2010	Adult	Not Specified
Insects	NESP	0.549	---	---	CEE-TV	Adult	Not Specified
Not Specified	SOSP	0.56	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.56	---	---	CEE-TV	Adult	Not Specified
Omnivore	CLRA	0.56	0.15	1.43	Ackerman et al., 2012	Adult	Not Specified
Insects	NESP	0.561	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.562	---	---	CEE-TV	Adult	Not Specified
Insects	NRWS	0.57	---	---	CEE-TV	Adult	Not Specified
Insects	SESP	0.57	---	---	Warner et al., 2010	Adult	Not Specified
Fish	BCNH	0.58	0.46	0.9	Hoffman et al., 2009	Adult	Not Specified
Fish	COLO	0.58	---	---	Kenow et al., 2007	Nestling/chick	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Aquatic Inverts	RUTU	0.587	0.3	1.73	Hargreaves et al., 2011	Adult	Not Specified
Fish	NOGA	0.592	---	---	CEE-TV	Adult	Not Specified
Insects	NESP	0.60	---	---	CEE-TV	Adult	Not Specified
Insects	SESP	0.6	---	---	Warner et al., 2010	Adult	Not Specified
Insects	SALS	0.61	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.61	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.62**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Fish	NOGA	0.623	---	---	CEE-TV	Adult	Not Specified
Insects	NESP	0.626	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	0.636	---	---	CEE-TV	Adult	Not Specified
Fish	COTE	0.64	---	---	Eisler, 1981	Adult	Biological Effects-Abnormal feathers
Insects	SALS	0.65	---	---	CEE-TV	Adult	Not Specified
Seeds	NOCA	0.66	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.67	0.63	0.7	Lane et al., 2011	Adult	Not Specified
Fish	RTLO	0.68	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	0.68	0.2	1.4	Jackson et al., 2011	Adult	Not Specified
Insects	SOSP	0.68	0.2	1.4	Jackson et al., 2011	Adult	Contaminated Site
Not Specified	bird	0.70	---	---	CEE-TV	Adult	Contaminated Site
Fish	BAEA	0.701	---	---	CEE-TV	Adult	Not Specified
Fish	DCCO	0.703	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.71	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.72	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	0.727	---	---	CEE-TV	Adult	Not Specified
Insects	NESP	0.73	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.73	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	0.735	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	NOGA	0.74	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.74	---	---	CEE-TV	Adult	Not Specified
Insects	CARW	0.75	0.4	0.9	Jackson et al., 2011	Adult	Not Specified
Insects	CARW	0.75	0.4	0.9	Jackson et al., 2011	Adult	Contaminated Site
Fish	COLO	0.75	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	0.75	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.751	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.76	---	---	CEE-TV	Adult	Not Specified
Fish	FOTE	0.77	---	---	Ackerman et al., 2008	Adult	Not Specified
Insects	SALS	0.77	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.79	---	---	CEE-TV	Adult	Not Specified
Omnivore	**CLRA**	**0.79**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Fish	BRPE	0.8	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.805	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.809	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	0.813	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	0.82	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	0.82	0.1	1.3	Jackson et al., 2011	Adult	Not Specified
Insects	SOSP	0.82	0.1	1.3	Jackson et al., 2011	Adult	Contaminated Site
Fish	COLO	0.83	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.83	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.85	---	---	CEE-TV	Adult	Not Specified
Insects	NESP	0.867	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	0.875	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	0.88	---	---	CEE-TV	Adult	Not Specified
Insects	CARW	0.9	0.5	1.4	Jackson et al., 2011	Adult	Not Specified
Insects	CARW	0.9	0.5	1.4	Jackson et al., 2011	Adult	Contaminated Site
Insects	INBU	0.9	---	---	CEE-TV	Adult	Not Specified
Fish	FOTE	0.91	---	---	Ackerman et al., 2008	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	OSPR	0.92	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	0.93	---	---	CEE-TV	Juv/sub adult	Biological Effects-Healthy
Fish	NOGA	0.937	---	---	CEE-TV	Adult	Not Specified
Fish	FOTE	0.97	---	---	Ackerman et al., 2008	Adult	Not Specified
Insects	GRCA	0.98	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	0.98	0.6	1.4	Jackson et al., 2011	Adult	Not Specified
Insects	SOSP	0.98	0.6	1.4	Jackson et al., 2011	Adult	Contaminated Site
Fish	NOGA	0.983	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	BNST	0.99	---	---	Eagles-smith et al., 2008	Nestling/chick	Not Specified
Aquatic Inverts	BNST	0.99	---	---	Ackerman, et al., 2011	Nestling/chick	Not Specified
Fish	NOGA	0.995	---	---	CEE-TV	Adult	Not Specified
Fish	BCNH	1.0	0.8	1.37	Hoffman et al., 2009	Adult	Not Specified
Herbivore	NOSH	1	0.2	1.5	Raygoza-Viera et al., 2013	Adult	Not Specified
Fish	COLO	1.01	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	1.02	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	1.06	---	---	CEE-TV	Adult	Not Specified
Fish	CLGR	1.06	0.2	8	Ackerman et al., 2015	Adult	Not Specified
Fish	COLO	1.08	---	---	CEE-TV	Adult	Not Specified
Insects	SALS	1.08	---	---	CEE-TV	Adult	Not Specified
Insects	CARW	1.09	0.4	1.7	Jackson et al., 2011	Adult	Not Specified
Insects	CARW	1.09	0.4	1.7	Jackson et al., 2011	Adult	Contaminated Site
Aquatic Inverts	BNST	1.09	0.3	6.000	Ackerman et al., 2007	Adult	Not Specified
Aquatic Inverts	BNST	1.09	---	---	Ackerman et al., 2007	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	SALS	1.09	---	---	CEE-TV	Adult	Not Specified
Insects	CARW	1.1	0.41	1.79	Schulwitz et al., 2015	Adult	Not Specified
Fish	OSPR	1.15	---	---	CEE-TV	Adult	Not Specified
Insects	REVI	1.17	0.9	1.5	Jackson et al., 2011	Adult	Not Specified
Insects	REVI	1.17	0.9	1.5	Jackson et al., 2011	Adult	Contaminated Site
Insects	CARW	1.18	0.2	2.3	Jackson et al., 2011	Adult	Not Specified
Insects	CARW	1.18	0.2	2.3	Jackson et al., 2011	Adult	Contaminated Site
Fish	COLO	1.19	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	1.2	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	1.2	---	---	Eisler, 2000	Adult	Contaminated Site
Insects	EABL	1.21	---	---	CEE-TV	Adult	Not Specified
Seeds	MALL	1.21	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	1.22	---	---	CEE-TV	Adult	Not Specified
Insects	REVI	1.22	0.6	1.8	Jackson et al., 2011	Adult	Not Specified
Insects	REVI	1.22	0.6	1.8	Jackson et al., 2011	Adult	Contaminated Site
Insects	SALS	1.24	---	---	CEE-TV	Adult	Not Specified
Insects	RBWO	1.27	---	---	CEE-TV	Adult	Not Specified
Fish	GBHE	1.3	---	---	Eisler, 2000	Adult	Contaminated Site
Insects	REVI	1.31	0.7	1.8	Jackson et al., 2011	Adult	Not Specified
Insects	REVI	1.31	0.7	1.8	Jackson et al., 2011	Adult	Contaminated Site
Insects	SALS	1.32	0.57	3	Lane et al., 2011	Adult	Not Specified
Insects	SALS	1.38	---	---	CEE-TV	Adult	Not Specified
Insects	EABL	1.39	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	1.47	---	---	CEE-TV	Adult	Not Specified
Insects	REVI	1.47	0.6	2.5	Jackson et al., 2011	Adult	Not Specified
Insects	REVI	1.47	0.6	2.5	Jackson et al., 2011	Adult	Contaminated Site
Aquatic Inverts	AMAV	1.49	---	---	Eagles-smith et al., 2008	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Aquatic Inverts	AMAV	1.49	---	---	Eagles-Smith et al., 2008	Adult	Not Specified
Fish	COLO	1.5	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	1.5	0.1	6.7	Eisler, 2000	Adult	Not Specified
Insects	REVI	1.52	0.6	2.9	Jackson et al., 2011	Adult	Not Specified
Insects	REVI	1.52	0.6	2.9	Jackson et al., 2011	Adult	Contaminated Site
Fish	BCNH	1.61	0.58	4.63	Hoffman et al., 2009	Adult	Not Specified
Insects	SOSP	1.63	---	---	Jackson et al., 2011	Adult	Not Specified
Insects	SOSP	1.63	---	---	Jackson et al., 2011	Adult	Contaminated Site
Insects	SALS	1.65	---	---	CEE-TV	Adult	Not Specified
Fish	FOTE	1.66	---	---	Ackerman et al., 2008	Adult	Not Specified
Fish	BAEA	1.66	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	COLO	1.7	---	---	CEE-TV	Adult	Not Specified
Fish	FOTE	1.71	---	---	Eagles-smith et al., 2008	Nestling/chick	Not Specified
Fish	FOTE	1.71	---	---	Ackerman, et al., 2011	Nestling/chick	Not Specified
Fish	COLO	1.74	---	---	CEE-TV	Adult	Biological Effects-Healthy
Fish	COLO	1.75	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	1.75	---	---	CEE-TV	Adult	Not Specified
Fish	NOGA	1.78	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	1.9	0.4	7.8	Eisler, 2000	Adult	Not Specified
Fish	OSPR	1.9	---	---	Eisler, 2000	Nestling/chick	Contaminated Site
Insects	SALS	1.94	---	---	CEE-TV	Adult	Not Specified
Fish	SVALBARD BLACK-LEGGED KITTIWAKE	1.97	1.53	2.41	Goutte et al., 2015	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	BAEA	1.98	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	1.98	---	---	Kenow et al., 2007	Nestling/chick	Not Specified
Fish	COLO	2	---	---	CEE-TV	Adult	Not Specified
Fish	SVALBARD BLACK-LEGGED KITTIWAKE	2.01	1.6	2.42	Goutte et al., 2015	Adult	Not Specified
Aquatic Inverts	AMAV	2.02	---	---	Eagles-Smith et al., 2009	Adult	Not Specified
Aquatic Inverts	AMAV	2.02	---	---	Eagles-smith et al., 2008	Nestling/chick	Not Specified
Fish	SVALBARD BLACK-LEGGED KITTIWAKE	2.06	1.62	2.50	Goutte et al., 2015	Adult	Not Specified
Insects	TUTI	2.07	---	---	CEE-TV	Adult	Not Specified
Fish	COLO	2.1	0.9	4.3	Eisler, 2000	Adult	Not Specified
Fish	NOGA	2.25	---	---	CEE-TV	Adult	Not Specified
Fish	BCNH	2.26	0.88	5.74	Hoffman et al., 2009	Adult	Not Specified
Carnivore	EASO	2.26	---	---	CEE-TV	Adult	Not Specified
Fish	SVALBARD BLACK-LEGGED KITTIWAKE	2.33	1.78	2.88	Goutte et al., 2015	Adult	Not Specified
Fish	COLO	2.38	---	---	CEE-TV	Adult	Not Specified
Insects	HOWR	2.38	---	---	CEE-TV	Adult	Not Specified
Omnivore	HEGU	2.42	---	---	trace metal concentrations in marine organisms	Adult	Not Specified
Omnivore	HEGU	2.42	---	---	Eisler, 2010	Adult	Not Specified
Insects	TRSW	2.51	---	---	CEE-TV	Adult	Contaminated Site
Fish	COLO	2.52	---	---	CEE-TV	Adult	Not Specified
Insects	NRWS	2.66	---	---	CEE-TV	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	SOSP	2.69	---	---	CEE-TV	Adult	Not Specified
Insects	CARW	2.77	1.59	5.62	Jackson et al., 2011	Adult	Not Specified
Insects	CARW	2.77	1.59	5.62	Jackson et al., 2011	Adult	Contaminated Site
Fish	COLO	2.78	---	---	CEE-TV	Adult	Not Specified
Insects	EAPH	3.24	---	---	CEE-TV	Adult	Not Specified
Insects	TRSW	3.25	---	---	CEE-TV	Adult	Contaminated Site
Fish	BEKI	3.35	---	---	CEE-TV	Adult	Not Specified
Fish	BAEA	3.39	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	TRSW	3.56	---	---	CEE-TV	Adult	Not Specified
Insects	TRSW	3.66	---	---	CEE-TV	Adult	Not Specified
Fish	SOTE	4.47	---	---	CEE-TV	Adult	Not Specified
Insects	CARW	4.49	---	---	CEE-TV	Adult	Not Specified
Fish	BFAL	4.5	3.4	6.4	Finkelstein et al., 2007	Adult	Not Specified
Fish	COLO	5	---	---	CEE-TV	Adult	Not Specified
Aquatic Inverts	BNST	5.05	---	---	Ackerman, et al., 2011	Adult	Not Specified
Aquatic Inverts	BNST	5.05	---	---	Eagles-smith et al., 2008	Adult	Not Specified
Fish	BAEA	5.41	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	BAEA	5.43	---	---	CEE-TV	Juv/sub adult	Not Specified
Fish	BAEA	6.27	---	---	CEE-TV	Juv/sub adult	Not Specified
Insects	REVI	6.72	---	---	CEE-TV	Adult	Not Specified
Fish	CATE	6.83	---	---	Eagles-smith et al., 2008	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	CATE	6.83	---	---	Ackerman, et al., 2011	Adult	Not Specified
Fish	FOTE	7.06	---	---	Eagles-smith et al., 2008	Adult	Not Specified
Fish	FOTE	7.06	---	---	Ackerman, et al., 2011	Adult	Not Specified
Fish	BCNH	7.38	3.7	16	Hoffman et al., 2009	Adult	Not Specified
Fish	COLO	7.67	---	---	Kenow et al., 2007	Nestling/chick	Not Specified
Fish	BAEA	13.1	---	---	CEE-TV	Adult	Not Specified

Table H.7: Whole blood nickel values in parts per million (ppm) w/w for select avian species and clapper rails in this study. Values are written as they appear in the literature, and values from this study are in boldface

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Seeds	MALL	---	0.00	1.2	Binkowski and Meissner, 2013	Adult	Contaminated Site
Seeds	MALL	---	0.00	1.7	Binkowski and Meissner, 2013	Adult	Reference Site
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Not Specified
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Reference Site
Fish	BCNH	0.0	---	---	CEE-TV	Nestling/chick	Not Specified
Insects	SOSP	0.03	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	SOSP	0.03	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	SOSP	0.04	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	SOSP	0.04	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	SOSP	0.08	---	---	Rhodes et al., 2015	Adult	Contaminated Site
Aquatic Inverts	BNST	0.11	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	BRTH	0.11	---	---	Rhodes et al., 2015	Adult	Not Specified
Seeds	MODO	0.13	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	**CLRA**	**0.13**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Insects	SOSP	0.14	---	---	Lester and Riper, 2014	Adult	Reference Site
Aquatic Inverts	AMAV	0.16	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	EATO	0.16	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	**CLRA**	**0.19**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**0.19**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	EABL	0.21	0.13	0.34	McQuiston, 2002	Adult	Not Specified
Omnivore	**CLRA**	**0.22**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Insects	EABL	0.23	0.17	0.31	McQuiston, 2002	Adult	Contaminated Site
Omnivore	**CLRA**	**0.26**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**0.33**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Insects	TRSW	0.34	0.26	0.45	McQuiston, 2002	Adult	Contaminated Site
Insects	TRSW	0.37	0.28	0.5	McQuiston, 2002	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	EATO	0.37	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	**CLRA**	**0.40**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**0.45**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**0.58**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**0.61**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**0.88**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**1.31**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**3.99**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**4.21**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**8.70**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**

Table H.8: Whole blood zinc values in parts per million (ppm) w/w for select avian species and clapper rails in this study. Values are written as they appear in the literature, and values from this study are in boldface

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Seeds	MALL	---	0.0	24.0	Binkowski and Meissner, 2013	Adult	Contaminated Site
Seeds	MALL	---	8.0	16.0	Binkowski and Meissner, 2013	Adult	Reference Site
Fish	OSPR	---	2.408	4.819	Langner et al., 2012	Nestling/chick	Not Specified
Not Specified	BIRD	---	---	>2	Merck Veterinary Online Manual	Not Specified	Biological Effects-Diagnostic of zinc toxicosis
Omnivore	**CLRA**	**0.00**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Fish	WOST	0.27	0.1075	0.3967	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Omnivore	**CLRA**	**0.48**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Not Specified	GLIB	0.9	0.7	1.3	Benito et al., 1999	Adult	Not Specified
Omnivore	**CLRA**	**1.56**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	GRFL	1.7	0.3	2.6	Benito et al., 1999	Adult	Not Specified
Seeds	PSITTACINE*	1.74	---	---	Rosenthal et al., 2005	Adult	Reference Site
Omnivore	**CLRA**	**1.78**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Carnivore	NOGO	1.8	1.29	2.3	Stout et al., 2010	Adult	Not Specified
Seeds	PSITTACINE*	1.82	---	---	Rosenthal et al., 2005	Adult	Reference Site
Fish	WHST	1.9	0.8	2.8	Benito et al., 1999	Adult	Not Specified
Seeds	PSITTACINE*	2.19	---	---	Rosenthal et al., 2005	Adult	Reference Site
Fish	GCGR	2.2	1.3	2.9	Benito et al., 1999	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Fish	GRAY HERON	2.2	1.5	3.3	Benito et al., 1999	Adult	Not Specified
Fish	WOST	2.312	1.845	2.724	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Omnivore	PUGA	2.44	---	---	CEE-TV	Adult	Not Specified
Fish	WOST	2.814	2.541	3.244	de la Casa-Resino et al., 2014	Nestling/chick	Not Specified
Omnivore	**CLRA**	**3.09**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Fish	SPOONBILL	3.2	1.4	5.5	Benito et al., 1999	Adult	Not Specified
Carnivore	BLKI	3.3	2.3	4.5	Benito et al., 1999	Adult	Not Specified
Seeds	MALL	3.3	1.3	4.00	Benito et al., 1999	Adult	Not Specified
Carnivore	BLVU*	3.5	0.4	9.0	Bravo and Colina, 2005	Adult	Not Specified
Aquatic Inverts	POCH	3.7	2.5	6.00	Benito et al., 1999	Adult	Not Specified
Aquatic Inverts	AMAV	3.83	---	---	Rhodes et al., 2015	Adult	Not Specified
Herbivore	MUSW	3.93	2.42	5.23	Day et al., 2003	Adult	Reference Site
Fish	BFALBA	4.2	3.8	4.8	Finkelstein et al., 2007	Adult	Not Specified
Fish	BCNH	4.32	---	---	CEE-TV	Nestling/chick	Not Specified
Fish	BCNH	4.36	---	---	CEE-TV	Nestling/chick	Reference Site
Fish	BCNH	4.37	---	---	CEE-TV	Nestling/chick	Not Specified
Omnivore	YLGU	4.4	3.1	5.2	Benito et al., 1999	Adult	Not Specified
Herbivore	MUSW	5.2	3.7	8.8	Eisler, 1993	Adult	Not Specified
Herbivore	TRUS	5.2	3.7	8.8	Eisler, 2000	Adult	Not Specified
Insects	EABL	5.25	4.69	5.89	McQuiston, 2002	Adult	Not Specified

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Omnivore	**CLRA**	**5.37**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Insects	EABL	5.53	4.61	6.63	McQuiston, 2002	Adult	Contaminated Site
Omnivore	**CLRA**	**5.64**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Herbivore	GADW	5.9	3.5	8.6	Benito et al., 1999	Adult	Not Specified
Insects	TRSW	6.02	5.08	7.13	McQuiston, 2002	Adult	Not Specified
Insects	TRSW	6.15	5.54	6.83	McQuiston, 2002	Adult	Contaminated Site
Insects	PIFL	6.2	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Aquatic Inverts	BNST	6.24	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	EATO	6.32	---	---	Rhodes et al., 2015	Adult	Not Specified
Insects	PIFL	6.4	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	SOSP	6.425	---	---	Lester and Riper, 2014	Adult	Not Specified
Aquatic Inverts	LESC	6.63	---	---	CEE-TV	Adult	Not Specified
Insects	SOSP	6.831	---	---	Lester and Riper, 2014	Adult	Not Specified
Omnivore	**CLRA**	**7.11**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Insects	SOSP	7.132	---	---	Lester and Riper, 2014	Adult	Reference Site
Carnivore	WTEA	7.5	---	---	Eisler, 1993	Adult	Not Specified
Carnivore	WTEA	7.5	---	---	Eisler, 2000	Adult	Not Specified
Insects	SOSP	7.509	---	---	Lester and Riper, 2014	Adult	Contaminated Site
Omnivore	BRTH	7.52	---	---	Rhodes et al., 2015	Adult	Not Specified
Seeds	MODO	7.66	---	---	Rhodes et al., 2015	Adult	Not Specified
Omnivore	EATO	7.93	---	---	Rhodes et al., 2015	Adult	Not Specified
Insects	PIFL	8.1	---	---	Berglund and Nyholm, 2011	Adult	Reference Site

Diet	AOU Code	Mean	Low Range	High Range	Reference Source	Age	Site Status
Insects	SOSP	8.219	---	---	Lester and Riper, 2014	Adult	Not Specified
Insects	PIFL	8.5	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	PIFL	9.1	---	---	Berglund and Nyholm, 2011	Adult	Contaminated Site
Insects	SOSP	9.606	---	---	Lester and Riper, 2014	Adult	Not Specified
Omnivore	**CLRA**	**13.58**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**14.01**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**14.41**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Seeds	BLUE AND GOLD MACAW*	15.5	---	---	Eisler, 1993	Adult	Biological Effects-Exhibited signs of zinc toxicosis
Omnivore	**CLRA**	**42.42**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**50.65**	**---**	**---**	**This study**	**Adult**	**Not Specified**
Omnivore	**CLRA**	**55.01**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**
Omnivore	**CLRA**	**56.93**	**---**	**---**	**This study**	**Juv/sub adult**	**Not Specified**

Table H.9: Metal values in parts per million (ppm) d/w for select invertebrate species, and composite invertebrate samples in this study. Values are written as they appear in the literature, and values from this study are in boldface.

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Arsenic	Mangrove periwinkle (*Littoraria scabra*)	1.1	---	---	Soft parts	Uncontaminated Site	Eisler, 2010
Arsenic	Mangrove periwinkle (*Littoraria scabra*)	1.4	---	---	Soft parts	Uncontaminated Site	Eisler, 2010
Arsenic	Common periwinkle (*Littorina littorea*)	4.0	---	---	Soft parts	Uncontaminated Site	Eisler, 1981
Arsenic	Mangrove periwinkle (*Littoraria scabra*)	6.5	---	---	Soft parts	Contaminanted Site	Eisler, 2010
Arsenic	Common periwinkle (*Littorina littorea*)	7.96	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Arsenic	Common periwinkle (*Littorina littorea*)	11.5	---	---	Soft parts	Contaminanted Site	Eisler, 1981
Arsenic	Common periwinkle (*Littorina littorea*)	12.94	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Arsenic	Common periwinkle (*Littorina littorea*)	16	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Arsenic	**Littorina spp., Ilyanassa spp., Sesarma spp., and Uca spp.**	**16.22**	**2.69**	**25.49**	**Whole**	**Not Specified**	**This study**
Arsenic	Common periwinkle (*Littorina littorea*)	16.4	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Arsenic	Common periwinkle (*Littorina littorea*)	19.6	3.2	73.0	Soft parts	Not Specified	Eisler, 1981
Arsenic	Common periwinkle (*Littorina littorea*)	20.43	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Arsenic	Common periwinkle (*Littorina littorea*)	20.62	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Arsenic	Common periwinkle (*Littorina littorea*)	22.92	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Arsenic	Marsh crab (*Sesarma erythodactyla*)	---	---	7.2	Soft parts	Contaminated Site	Eisler, 2010
Arsenic	Marsh crab (*Sesarma erythodactyla*)	---	---	32.6	Soft parts	Contaminated Site	Eisler, 2010

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Cadmium	Littorina sp.	0.8	---	---	Soft parts	Not Specified	Eisler, 1981
Cadmium	**Littorina spp., Ilyanassa spp., Sesarma spp., and Uca spp.**	**0.89**	**0.27**	**1.36**	**Whole**	**Not Specified**	**This study**
Cadmium	Common periwinkle (*Littorina littorea*)	0.92	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Cadmium	Mangrove periwinkle (*Littoraria scabra*)	1.0	---	---	Soft parts	Uncontaminated Site	Eisler, 2010
Cadmium	Common periwinkle (*Littorina littorea*)	1.43	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Cadmium	Common periwinkle (*Littorina littorea*)	1.56	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Cadmium	Mangrove periwinkle (*Littoraria scabra*)	1.7	---	---	Soft parts	Contaminanted Site	Eisler, 2010
Cadmium	Common periwinkle (*Littorina littorea*)	2.19	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Cadmium	Mangrove crab (*Sesarma mederi*)	3.08	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Cadmium	Mangrove crab (*Sesarma mederi*)	3.56	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Cadmium	Mangrove crab (*Sesarma mederi*)	3.74	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Cadmium	Common periwinkle (*Littorina littorea*)	3.78	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Cadmium	Mangrove crab (*Sesarma mederi*)	3.92	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Cadmium	Mangrove crab (*Sesarma mederi*)	3.95	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Cadmium	Mangrove crab (*Sesarma mederi*)	4.49	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Cadmium	Common periwinkle (*Littorina littorea*)	4.51	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Cadmium	Common periwinkle (*Littorina littorea*)	5.23	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Cadmium	Mangrove periwinkle (*Littoraria scabra*)	10.0	---	---	Soft parts	Contaminanted Site	Eisler, 2010
Cadmium	Common periwinkle (*Littorina littoralis*)	178.0	---	---	Soft parts	Not Specified	Eisler, 1981
Cadmium	Periwinkle (*Littoraria littorea*)	210.0	---	---	Soft parts	Not Specified	Eisler, 2010
Cadmium	Marsh crab (*Sesarma erythodactyla*)	---	---	22.5	Soft parts	Contaminated Site	Eisler, 2010
Cadmium	Marsh crab (*Sesarma erythodactyla*)	---	---	25.9	Soft parts	Contaminated Site	Eisler, 2010
Cadmium	Periwinkle (*Littoraria littorea*)	---	0.9	1.5	Soft parts	Not Specified	Eisler, 2010
Cadmium	Common periwinkle (*Littorina littorea*)	---	0.94	1.5	Soft parts	Not Specified	Eisler, 1981
Cadmium	Common periwinkle (*Littorina littorea*)	---	0.49	2.56	Soft parts with operculum	Not Specified	Eisler, 1981
Cadmium	Common periwinkle (*Littorina littorea*)	---	0.9	1.5	Soft parts	Not Specified	Eisler, 1985
Cadmium	Common periwinkle (*Littorina littorea*)	---	0.0	0.5	Soft parts	Not Specified	Eisler, 1985
Cadmium	Common periwinkle (*Littorina littorea*)	---	---	210.0	Soft parts	Not Specified	Eisler, 1985
Chromium	Common periwinkle (*Littorina littorea*)	0.11	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Chromium	Common periwinkle (*Littorina littorea*)	0.23	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Chromium	Common periwinkle (*Littorina littorea*)	0.53	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Chromium	Common periwinkle (*Littorina littorea*)	0.87	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Chromium	Common periwinkle (*Littorina littorea*)	0.92	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Chromium	Common periwinkle (*Littorina littorea*)	1.34	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Chromium	Common periwinkle (*Littorina littorea*)	1.48	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Chromium	Mangrove periwinkle (*Littoraria scabra*)	4.0	---	---	Soft parts	Uncontaminated Site	Eisler, 2010

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Chromium	Mangrove periwinkle (*Littoraria scabra*)	7.0	---	---	Soft parts	Contaminanted Site	Eisler, 2010
Chromium	Mangrove periwinkle (*Littoraria scabra*)	8.5	---	---	Soft parts	Contaminanted Site	Eisler, 2010
Chromium	**Littorina spp., Ilyanassa spp., Sesarma spp., and Uca spp.**	**9.64**	**1.09**	**35.19**	**Whole**	**Not Specified**	**This study**
Chromium	Marsh crab (*Sesarma erythodactyla*)	---	---	3.5	Soft parts	Contaminated Site	Eisler, 2010
Chromium	Marsh crab (*Sesarma erythodactyla*)	---	---	4.5	Soft parts	Contaminated Site	Eisler, 2010
Chromium	Common periwinkle (*Littorina littorea*)	---	<0.1	1.6	Soft parts	Not Specified	Eisler, 2000
Chromium	Common periwinkle (*Littorina littorea*)	---	0.1	1.0	Soft parts with operculum	Not Specified	Eisler, 1981
Chromium	Common periwinkle (*Littorina littorea*)	---	<0.1	1.6	Soft parts	Not Specified	Eisler, 1986
Chromium	Common periwinkle (*Littorina littorea*)	----	0.1	1.6	Soft parts	Not Specified	Eisler, 2000
Copper	Mangrove crab (*Sesarma mederi*)	1.3	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Copper	Mangrove crab (*Sesarma mederi*)	1.48	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Copper	Mangrove crab (*Sesarma mederi*)	1.71	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Copper	Mangrove crab (*Sesarma mederi*)	1.74	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Copper	Mangrove crab (*Sesarma mederi*)	1.86	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Copper	Mangrove crab (*Sesarma mederi*)	2.1	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Copper	Mangrove periwinkle (*Littoraria scabra*)	8.0	---	---	Soft parts	Uncontaminated Site	Eisler, 2010
Copper	Mangrove periwinkle (*Littoraria scabra*)	9.0	---	---	Soft parts	Contaminanted Site	Eisler, 2010

Parameter	**Species**	**Mean**	**Low Range**	**High Range**	**Sample Type**	**Site Status**	**Reference Source**
Copper	Fiddler crab (*Uca pugnax*)	16.7	---	---	Exoskeleton	Reference Site	Eisler, 2010
Copper	**Littorina spp., Ilyanassa spp., Sesarma spp., and Uca spp.**	**59.84**	**2.37**	**130.26**	**Whole**	**Not Specified**	**This study**
Copper	Mangrove periwinkle (*Littoraria scabra*)	62.0	---	---	Soft parts	Contaminanted Site	Eisler, 2010
Copper	Common periwinkle (*Littorina littorea*)	68.22	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Copper	Fiddler crab (*Uca pugnax*)	75.3	---	---	Exoskeleton	Contaminated Site	Eisler, 2010
Copper	Common periwinkle (*Littorina littorea*)	75.59	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Copper	Common periwinkle (*Littorina littorea*)	110	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Copper	Common periwinkle (*Littorina littorea*)	119	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Copper	Common periwinkle (*Littorina littorea*)	124.0	62.0	194.0	Soft parts with operculum	Not Specified	Eisler, 1981
Copper	Common periwinkle (*Littorina littorea*)	127	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Copper	Fiddler crab (*Uca pugnax*)	136.6	---	---	Carapace	Reference Site	Eisler, 2010
Copper	Common periwinkle (*Littorina littorea*)	138	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Copper	Fiddler crab (*Uca pugnax*)	152.7	---	---	Carapace	Contaminated Site	Eisler, 2010
Copper	Common periwinkle (*Littorina littorea*)	176	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Copper	Fiddler crab (*Uca pugnax*)	194.4	---	---	Soft tissue	Reference Site	Eisler, 2010
Copper	Fiddler crab (*Uca pugnax*)	306.5	---	---	Soft tissue	Contaminated Site	Eisler, 2010
Copper	Fiddler crab (*Uca pugnax*)	518.9	---	---	Soft tissue	Reference Site	Eisler, 2010
Copper	Fiddler crab (*Uca pugnax*)	639.7	---	---	Soft tissue	Contaminated Site	Eisler, 2010

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Copper	Marsh crab (*Sesarma erythodactyla*)	---	---	86.8	Soft parts	Contaminated Site	Eisler, 2010
Copper	Marsh crab (*Sesarma erythodactyla*)	---	---	239.0	Soft parts	Contaminated Site	Eisler, 2010
Copper	Common periwinkle (*Littorina littorea*)	---	42.7	248.8	Soft parts	Not Specified	Eisler, 1981
Copper	Common periwinkle (*Littorina littorea*)	---	91.4	92.5	Digestive gland and gonad	Not Specified	Eisler, 1981
Copper	Common periwinkle (*Littorina littorea*)	---	2.1	3.5	Shell	Not Specified	Eisler, 1981
Lead	Mangrove periwinkle (*Littoraria scabra*)	0.8	---	---	Soft parts	Uncontaminated Site	Eisler, 2010
Lead	Common periwinkle (*Littorina littorea*)	0.86	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Lead	Common periwinkle (*Littorina littorea*)	0.87	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Lead	Common periwinkle (*Littorina littorea*)	1.01	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Lead	Common periwinkle (*Littorina littorea*)	1.15	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Lead	Common periwinkle (*Littorina littorea*)	1.6	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Lead	Mangrove periwinkle (*Littoraria scabra*)	1.6	---	---	Soft parts	Contaminanted Site	Eisler, 2010
Lead	Common periwinkle (*Littorina littorea*)	1.67	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Lead	Mangrove crab (*Sesarma mederi*)	2.51	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Lead	Common periwinkle (*Littorina littorea*)	3.0	---	---	Soft parts	Not Specified	Eisler, 1981
Lead	Mangrove crab (*Sesarma mederi*)	3.27	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Lead	**Littorina spp., Ilyanassa spp., Sesarma spp., and Uca spp.**	**3.47**	**0.30**	**11.53**	**Whole**	**Not Specified**	**This study**
Lead	Mangrove crab (*Sesarma mederi*)	5.41	---	---	Whole	Contaminated Site	Chaiyara et al., 2013

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Lead	Mangrove crab (*Sesarma mederi*)	6.1	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Lead	Mangrove crab (*Sesarma mederi*)	7.23	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Lead	Mangrove crab (*Sesarma mederi*)	7.88	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Lead	Mangrove periwinkle (*Littoraria scabra*)	8.2	---	---	Soft parts	Contaminanted Site	Eisler, 2010
Lead	Fiddler crab (*Uca pugnax*)	11.5	---	---	Soft tissue	Reference Site	Eisler, 2010
Lead	Fiddler crab (*Uca pugnax*)	18.3	---	---	Soft tissue	Contaminated Site	Eisler, 2010
Lead	Common periwinkle (*Littorina littorea*)	19.0	3.7	70.0	Soft parts	Not Specified	Eisler, 1981
Lead	Fiddler crab (*Uca pugnax*)	20.4	---	---	Soft tissue	Reference Site	Eisler, 2010
Lead	Fiddler crab (*Uca pugnax*)	27.00	---	---	Carapace	Reference Site	Eisler, 2010
Lead	Fiddler crab (*Uca pugnax*)	33.1	---	---	Exoskeleton	Reference Site	Eisler, 2010
Lead	Fiddler crab (*Uca pugnax*)	41.2	---	---	Carapace	Contaminated Site	Eisler, 2010
Lead	Fiddler crab (*Uca pugnax*)	41.4	---	---	Soft tissue	Contaminated Site	Eisler, 2010
Lead	Fiddler crab (*Uca pugnax*)	129.8	---	---	Exoskeleton	Contaminated Site	Eisler, 2010
Lead	Marsh crab (*Sesarma erythodactyla*)	---	---	132.0	Soft parts	Contaminated Site	Eisler, 2010
Lead	Marsh crab (*Sesarma erythodactyla*)	---	---	193.0	Soft parts	Contaminated Site	Eisler, 2010
Lead	Common periwinkle (*Littorina littorea*)	---	4.0	15.0	Soft parts	Not Specified	Eisler, 1981
Lead	Common periwinkle (*Littorina littorea*)	---	3.7	10.0	Digestive gland and gonad	Not Specified	Eisler, 1981
Lead	Common periwinkle (*Littorina littorea*)	---	28.8	41.5	Shell	Not Specified	Eisler, 1981
Mercury	Crab (Uca sp.)	0.04	---	---	Whole	Not Specified	Eisler, 2010

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Mercury	Common periwinkle (*Littorina littorea*)	0.11	---	---	Soft parts	Not Specified	Eisler, 1981
Mercury	Eastern mudsnail (*Ilyanassa obsolete*)	0.22	0.18	0.3	Soft tissues	Not Specified	Casazza, et al. 2014
Mercury	**Littorina spp., Ilyanassa spp., Sesarma spp., and Uca spp.**	**0.35**	**0.17**	**0.56**	**Whole**	**Not Specified**	**This study**
Mercury	Crab (Uca sp.)	0.4	---	---	Whole	Not Specified	Eisler, 1981
Mercury	Fiddler crab (*Uca pugnax*)	0.4	---	---	Whole	Contaminated Site	Cumbee et al., 2008
Mercury	Marsh Periwinkle (*Littorina irrorata*)	0.61	---	---	Soft parts	Not Specified	Eisler, 1981
Mercury	Eastern mudsnail (*Ilyanassa obsolete*)	0.7	0.55	0.85	Soft tissues	Not Specified	Casazza, et al. 2014
Mercury	Eastern mudsnail (*Ilyanassa obsolete*)	0.8	0.6	2.1	Soft tissues	Not Specified	Casazza, et al. 2014
Mercury	Eastern mudsnail (*Ilyanassa obsolete*)	0.8	0.55	1.1	Soft tissues	Not Specified	Casazza, et al. 2014
Mercury	Common periwinkle (*Littorina littoralis*)	1.84	---	---	Soft parts	Not Specified	Eisler, 1981
Mercury	Littorina sp.	2.6	---	---	Soft parts	Not Specified	Eisler, 1981
Nickel	Common periwinkle (*Littorina littorea*)	3.43	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Nickel	Common periwinkle (*Littorina littorea*)	3.91	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Nickel	Common periwinkle (*Littorina littorea*)	4.44	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Nickel	Common periwinkle (*Littorina littorea*)	4.6	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Nickel	Common periwinkle (*Littorina littorea*)	5.25	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Nickel	Common periwinkle (*Littorina littorea*)	6.13	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Nickel	Common periwinkle (*Littorina littorea*)	7.43	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Nickel	**Littorina spp., Ilyanassa spp., Sesarma spp., and Uca spp.**	**12.83**	**9.52**	**19.45**	**Whole**	**Not Specified**	**This study**

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Nickel	Common periwinkle (*Littorina littorea*)	---	2.1	4.1	Soft parts with operculum	Not Specified	Eisler, 1981
Silver	**Littorina spp., Ilyanassa spp., Sesarma spp., and Uca spp.**	**0.56**	**0.18**	**0.85**	**Whole**	**Not Specified**	**This study**
Silver	Common periwinkle (*Littorina littorea*)	0.81	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Silver	Common periwinkle (*Littorina littorea*)	0.82	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Silver	Common periwinkle (*Littorina littorea*)	1.42	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Silver	Common periwinkle (*Littorina littorea*)	1.69	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Silver	Common periwinkle (*Littorina littorea*)	2.07	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Silver	Common periwinkle (*Littorina littorea*)	3.92	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Silver	Common periwinkle (*Littorina littorea*)	4.1	3.4	5.0	Soft parts	Uncontaminated Site	Eisler, 2000
Silver	Common periwinkle (*Littorina littorea*)	4.1	3.4	5.0	Soft parts	Uncontaminated Site	Eisler, 2000
Silver	Common periwinkle (*Littorina littorea*)	4.1	3.4	5.0	Soft parts	Uncontaminated Site	Eisler, 1996
Silver	Common periwinkle (*Littorina littorea*)	4.85	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Silver	Common periwinkle (*Littorina littorea*)	10.7	3.1	17.4	Soft parts	Contaminanted Site	Eisler, 2000
Silver	Common periwinkle (*Littorina littorea*)	10.7	3.1	17.4	Soft parts	Contaminanted Site	Eisler, 2000
Silver	Common periwinkle (*Littorina littorea*)	10.7	3.1	17.4	Soft parts	Contaminanted Site	Eisler, 1996
Zinc	Mangrove crab (*Sesarma mederi*)	0.65	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Zinc	Mangrove crab (*Sesarma mederi*)	3.63	---	---	Whole	Contaminated Site	Chaiyara et al., 2013

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Zinc	Mangrove crab (*Sesarma mederi*)	3.83	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Zinc	Mangrove crab (*Sesarma mederi*)	4.00	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Zinc	Mangrove crab (*Sesarma mederi*)	4.58	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Zinc	Mangrove crab (*Sesarma mederi*)	4.93	---	---	Whole	Contaminated Site	Chaiyara et al., 2013
Zinc	Fiddler crab (*Uca pugnax*)	25.6	---	---	Exoskeleton	Reference Site	Eisler, 2010
Zinc	Common periwinkle (*Littorina littorea*)	38.0	---	---	Soft parts	Not Specified	Eisler, 1981
Zinc	Fiddler crab (*Uca pugnax*)	46.6	---	---	Carapace	Reference Site	Eisler, 2010
Zinc	Fiddler crab (*Uca pugnax*)	46.6	---	---	Carapace	Contaminated Site	Eisler, 2010
Zinc	Common periwinkle (*Littorina littorea*)	59.65	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Zinc	**Littorina spp., Ilyanassa spp., Sesarma spp., and Uca spp.**	**70.31**	**6.21**	**164.03**	**Whole**	**Not Specified**	**This study**
Zinc	Common periwinkle (*Littorina littorea*)	70.57	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Zinc	Fiddler crab (*Uca pugnax*)	79.6	---	---	Exoskeleton	Contaminated Site	Eisler, 2010
Zinc	Common periwinkle (*Littorina littorea*)	80	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Zinc	Common periwinkle (*Littorina littorea*)	86.23	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Zinc	Common periwinkle (*Littorina littorea*)	88.0	---	---	Soft parts	Not Specified	Eisler, 1981
Zinc	Common periwinkle (*Littorina littorea*)	93.21	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Zinc	Common periwinkle (*Littorina littorea*)	93.21	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000

Parameter	**Species**	**Mean**	**Low Range**	**High Range**	**Sample Type**	**Site Status**	**Reference Source**
Zinc	Mangrove periwinkle (*Littoraria scabra*)	95.0	---	---	Soft parts	Uncontaminated Site	Eisler, 2010
Zinc	Common periwinkle (*Littorina littorea*)	106	---	---	Soft tissues	Not Specified	De Wolf, et al. 2000
Zinc	Fiddler crab (*Uca pugnax*)	108.8	---	---	Soft tissue	Reference Site	Eisler, 2010
Zinc	Common periwinkle (*Littorina littorea*)	117.0	45.0	284.0	Soft parts with operculum	Not Specified	Eisler, 1981
Zinc	Common periwinkle (*Littorina littorea*)	120	---	---	Head/foot	Contaminanted Site	Eisler, 1993
Zinc	Fiddler crab (*Uca pugnax*)	133.3	---	---	Soft tissue	Contaminated Site	Eisler, 2010
Zinc	Fiddler crab (*Uca pugnax*)	149.8	---	---	Soft tissue	Reference Site	Eisler, 2010
Zinc	Fiddler crab (*Uca pugnax*)	165.8	---	---	Soft tissue	Contaminated Site	Eisler, 2010
Zinc	Common periwinkle (*Littorina littorea*)	255	---	---	Gills	Contaminanted Site	Eisler, 1993
Zinc	Common periwinkle (*Littorina littoralis*)	312.0	---	---	Soft parts	Not Specified	Eisler, 1981
Zinc	Common periwinkle (*Littorina littorea*)	372	---	---	Kidney	Uncontaminated Site	Eisler, 1993
Zinc	Common periwinkle (*Littorina littorea*)	605	---	---	Whole soft parts	Contaminanted Site	Eisler, 1993
Zinc	Mangrove periwinkle (*Littoraria scabra*)	750.0	---	---	Soft parts	Contaminanted Site	Eisler, 2010
Zinc	Common periwinkle (*Littorina littorea*)	1322	---	---	Viscera	Contaminanted Site	Eisler, 1993
Zinc	Common periwinkle (*Littorina littorea*)	1918	---	---	Stomach	Contaminanted Site	Eisler, 1993
Zinc	Common periwinkle (*Littorina littorea*)	2153	---	---	Kidney	Contaminanted Site	Eisler, 1993

Parameter	Species	Mean	Low Range	High Range	Sample Type	Site Status	Reference Source
Zinc	Marsh crab (*Sesarma erythodactyla*)	---	---	292.0	Soft parts	Contaminated Site	Eisler, 2010
Zinc	Marsh crab (*Sesarma erythodactyla*)	---	---	403.0	Soft parts	Contaminated Site	Eisler, 2010
Zinc	Common periwinkle (*Littorina littorea*)	---	---	<185	All tissues except kidneys	Uncontaminated Site	Eisler, 1993
Zinc	Common periwinkle (*Littorina littorea*)	---	---	520.0	Soft parts	Not Specified	Eisler, 1981
Zinc	Common periwinkle (*Littorina littorea*)	---	28.0	274.0	Soft parts	Not Specified	Eisler, 1981
Zinc	Common periwinkle (*Littorina littorea*)	---	92.1	186.0	Soft parts	Not Specified	Eisler, 1981
Zinc	Common periwinkle (*Littorina littorea*)	---	111.2	133.7	Digestive gland and gonad	Not Specified	Eisler, 1981
Zinc	Common periwinkle (*Littorina littorea*)	---	2.6	3.0	Shell	Not Specified	Eisler, 1981