Monitoring Wetland Integrity and Restoration Success with Avifauna in the Prairie Pothole Region of Alberta, Canada

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

In response to high wetland losses, and in recognition of the ecological functions and services provided by wetland ecosystems, updated wetland policy in Alberta focuses on protecting these important system and mitigating losses. A means to evaluate ecological health at wetlands in Alberta is needed to aid wetland protection in the province. With mitigation directed under the Alberta wetland policy, an evaluation of restoration progress is necessary to provide further guidance for wetland mitigation.

An index of biological integrity (IBI) is a commonly used multi-metric bioassessment tool that uses biological indicators to predict ecosystem integrity or health. I developed IBIs for the Grassland and Parkland regions of Alberta from metrics derived from the avian community. I additionally created an IBI for both regions, to determine if regionally specific IBIs were more appropriate. I evaluated the responsiveness of avian metrics to a disturbance index I created. I successfully created IBIs for each region. I found that separate IBIs were superior to a joint IBI due to regional differences in the reference condition between the Parkland and Grassland. However, I could not validate the Grassland IBI with an independent dataset, most likely due to inaccuracies in remotely sensed land cover data and a small sample size for validation.

To capture the current state of restored wetlands in the Parkland region, I compared the waterbird community composition in restored marshes to natural marshes that ranged a gradient in anthropogenic disturbance in the Parkland region of Alberta. I found that the avian community composition differed significantly between natural and restored wetlands. Restored wetlands had a unique assemblage of avian species. Using ordinations, I found strong support for an association of the waterbird community with both local- and landscape-level habitat variables.

My work will help guide restoration practices and highlights the potential risks posed by adoption of wetland mitigation banking programs.

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1 General introduction

1.1 Northern prairie pothole wetlands

Mineral marshes of the agriculturally dominated landscape in the northern extent of the Prairie Pothole Region (PPR) are of utmost ecological importance with a unique set of ecosystem functions and services driven by water fluctuations, including surface water storage (Hubbard and Linder, 1986), ground water recharge (Van der Kamp and Hayashi, 1998), and waterfowl and shorebird recruitment (Beyersbergen et al., 2004). Marshes are among the most productive habitats in the world, supporting a diversity of flora and fauna in addition to providing ecosystem services including flood mitigation, ground water recharge, contaminant filtration and carbon sequestration (Beyersbergen et al., 2004). Mineral wetlands are exceptionally productive with net productivity ranging from 1000 to 6000 g/m^2/yr (Mitsch and Gosselink, 2000). Wetland functions are degraded by encroaching agriculture, forestry, mining and urban development. The PPR and the mineral marsh wetlands within are regarded as the most important breeding habitat for waterfowl in North America (Beyersbergen et al., 2004), providing habitat to almost half of the continent's waterfowl (Batt et al., 1989).

The landscape of the PPR region was shaped by the retreat of glaciers, which left a gently undulating landscape from deposits of glacial till and melting ice blocks (Beyersbergen et al., 2004; Winter, 1989). Numerous small depressions are prevalent throughout the PPR, which are filled with marshes as a result of soils with a high clay content that prevent rapid water infiltration, and a lack of drainage pathways due to low topographic gradients (Winter, 1989). The resulting wetlands are often less than one hectare in size, shallow, and experience water fluctuations (Serran and Creed, 2016; van der Valk and Pederson, 2003). The region receives little precipitation, but experiences extremes in temperatures leading to a negative water balance. The wetlands of the region receive their main water inputs from spring snowmelt and rainfall that cannot infiltrate through the deep, frozen frost layer in early spring (Hayashi et al., 2016; Winter, 1989). Stewart and Kantrud's (1971) prairie wetland classification system is particularly useful in categorizing marshes in the PPR because of their naturally dynamic hydrologic cycles and frequent draw-downs. Within this system, there are four classes of non-permanent wetlands identified: Class I (ephemeral), Class II (temporary), Class III (seasonal), Class IV (semi-permanent). These non-permanent wetlands classes are the most frequent in the PPR (Beyersbergen et al., 2004; Wray and Bayley, 2006).

1.2 Wetland Policy

In response to the global recognition of the ecological functions of wetland systems and the need for conservation, the intergovernmental treaty called the Ramsar Convention was created in 1971 (UNESCO, 1994). Twenty years later, Canadian national wetland protection priorities were outlined (Government of Canada, 1991); however, the provinces have jurisdiction over more wetland resources than the federal government. Alberta was one of the first Canadian provinces to legislate a policy with the specific goal of conserving wetlands: their Interim Wetland Policy was released in 1993 (Clare and Creed, 2014). In 2013, the Government of Alberta replaced it with a more comprehensive Wetland Policy (2013), which recognizes the 'relative value' of individual wetlands on the landscape based on the functions they provide (Goverment of Alberta, 2013). The relative value of a wetland is to be evaluated by standardized metrics derived from five prioritized wetland functional groups; 1) biodiversity and ecological health; 2) water quality improvement; 3) hydrologic function; 4) human uses; and, 5) relative abundance (Government of Alberta, 2013). When any activity is proposed in or near a wetland, a wetland assessment is required to be conducted by a Qualified Wetland Science Practitioner (QWSP). A wetland assessment includes delineating the wetland area, determining the wetland class, and assessing its wetland value using the Alberta Wetland Rapid Evaluation Tool (ABWRET). The ABWRET tool has been developed using metrics derived from the five function groups (Government of Alberta, 2014).

Furthermore, a mandate of the Alberta Wetland Policy is to direct conservation and restoration where wetland losses have been historically high. The most populated portion of Alberta is located in the Grassland and Parkland natural regions in Alberta, which make up the northern extent of the PPR. Wetlands in these regions have been the most severely altered and have experienced the highest losses (Wray and Bayley, 2006). The relatively flat topography, fertile soils, and climate of the PPR has made it a prime agricultural region. The majority of wetlands of this region have been degraded by surrounding agricultural practices, and many have been completely drained (Clare and Creed, 2014; Gleason et al., 2008).

1.3 Mitigation Policy

Globally, nearly all wetland policies incorporate a mitigation framework, wherein the conservation of existing wetlands is prioritized and compensation for wetland losses is mandated. Under the Alberta Wetland Policy (2013), compensation for lost wetland functions is mandated through the restoration, enhancement or creation of wetlands when losses are deemed unavoidable. The use of restoration to offset the loss of wetlands and their functions is based on the conceptual model that restoration can reverse the change in state of a system from an anthropogenically degraded state to a more pristine state. It is presumed that once environmental conditions are restored to pre-disturbance levels, the degradation trajectory can be reversed and the system can re-establish following successional processes (Dobson et al., 1997; Suding et al., 2004; Zedler and Callaway, 1999). This theory suggests that wetlands undergo a gradual change following a gradient from a pristine state to a degraded state, with restoration having the capacity to reverse this trajectory. This conceptual model has been challenged, with evidence that degraded systems exist in an alternative stable state that is resistant to recovery through restoration actions (Suding et al., 2004), or that there are multiple thresholds that impede the transition of a degraded system to a more pristine state (Hobbs, 2007). Wetland mitigation policy has existed in the United States since the early 1970's, and reviews of the success of mitigation wetlands at replacing wetland functions have been overwhelmingly negative (Brooks et al., 2005; Goldberg and Reiss, 2016; Gutrich et al., 2009; Gutrich and Hitzhusen, 2004; Hoeltje and Cole, 2007; Spieles et al., 2006; Whigham, 1999; Zedler and Callaway, 1999). However, some of the literature does suggest a more positive trajectory of recovery (Balcombe et al., 2005; Burgin, 2010; Spieles, 2005). Insightful recommendations for improving restoration efforts have emerged from both positive and negative assessments, furthering research into effective wetland restoration (Mitsch and Wilson, 1996; Zedler, 2000).

The Alberta Wetland Policy (2013) is innovative in that the area-ratio of restoration required per hectare of wetland habitat destroyed is not a fixed replacement ratio, or an area-based conversion, but an adjustable replacement ratio. The adjustable replacement ratio determines the total amount of compensation necessary based on the ABWRET-determined values of the lost and replacement wetlands. A wetland's value is determined based on the functions provided by the wetland to be eliminated and the assumed functions provided by the compensation wetland to be created or restored (Government of Alberta, 2013). The success of restoring ecological functions is influenced by the topography, soils, and hydrology of the site (Zedler and Kercher, 2005). Returning the natural cycle of fluctuating water levels to a restoration site is imperative and the functions provided by created wetlands are limited without major seasonal interventions. Additionally, due to the inherent natural variation of wetlands, predicting wetland functions of restored sites can be challenging (Zedler and Kercher, 2005).

Wetland restoration in the northern extent of the PPR in Alberta has been mainly carried out by Ducks Unlimited Canada (DU), after recognition in the early 1980s that most easily drained wetlands had been lost already (Gray et al., 1999). After the establishment of the North American Waterfowl Management Plan (NAWMP) in 1986, more targeted efforts were initiated to restore lost waterfowl habitat in the prairie provinces by DU. The overall goal of these efforts was to increase waterfowl recruitment (Gray et al., 1999). Wetland restoration within the Canadian extent of the PPR mainly involves the construction of ditch plugs, where an existing drainage ditch is plugged using soil (for wetlands <5 ha) or a water control structure (for wetlands > 5ha; Gray et al., 1999). In Alberta, the logistics for wetland restoration have differed slightly between the Grassland and Parkland regions due to differences in private land ownership. In the Parkland region, most wetland restoration is conducted on sections of land that were first purchased by DU with the intent to lease or re-sell the land with a conservation easement. In the Grassland region, less land is available for purchase and DU works directly with farmers, paying them compensation for converting marginal farmland to wetland habitat. The farmers sign an agreement to continue the protection of the wetland habitat for a set duration, and this agreement often includes a confidentiality clause (Tracy Scott, DU, personal communication). Consequently, studies into the success of restoration in the Grassland region are much more difficult to undertake, as there is no central inventory of wetlands that have been restored by DU and permission to access each restored wetland needs to be obtained from individual land owners.

Wetland restoration has the potential to improve biological functions and biodiversity in the region, but restoration monitoring is needed. A means to evaluate the biological integrity at these sites is required to support the successful implementation of the Alberta Wetland Policy (2013). Much research has been conducted on Prairie Pothole wetlands in the southern part of the PPR, but the wetlands in Alberta are less well researched, especially the biological components of non-permanent wetlands (Wray and Bayley, 2006).

1.4 Bioassessment

An ecosystem has integrity when it is functioning within the boundaries of natural variability as defined by minimally impacted reference sites (Karr and Chu, 1999; Rader, 2001; US EPA, 2002a). Indicators are used to measure wetland integrity because direct measurements of wetland functions, including biochemical and hydrologic processes, can be very difficult or even impossible to achieve. Indicators of wetland integrity can be divided into 3 categories: biological, chemical, and physical. Bioassessment has been used widely in environmental management, and refers to the use of biological indicators to monitor ecosystem health or integrity. Biological indicators have the advantage of responding to disturbance from chemical, physical, and biological origins (Karr and Chu, 1999). A useful biological indictor for bioassessment applications responds predictably to a gradient of environmental stress. Biological indicators are often favoured in ecological assessment, especially where multiple stressors are acting on a system and yielding cumulative effects (Karr and Chu, 1999).

1.4.1 Index of Biological Integrity

An Index of Biological Integrity (IBI) is a multi-metric index that uses biological indicators that respond to changes in environmental stress to evaluate the degree to which an ecosystem has deviated from the reference condition; i.e., the least anthropogenically disturbed or best available ecosystem state, in which the appropriate community composition is supported and ecological processes are occurring within the bounds of natural variability (Stoddard et al., 2006). The framework for developing IBIs has been well established in stream systems within the continental USA by Karr (1981), using fish communities as biological indicators. An IBI is developed through sampling sites over a gradient of human disturbance, from minimally affected 'reference' sites to highly degraded sites. Sampling many sites across the range of conditions makes it possible to evaluate the response of different biological metrics to disturbance or stress while incorporating natural variability (Karr and Chu, 1999). Metrics are attributes of the biological community (e.g., total taxon richness, number of sensitive species, relative abundance of omnivores, etc.) that are calculated from species presence and abundance data. An IBI uses the sum of multiple metrics (typically six to ten) that respond empirically to a gradient of human disturbance (Karr and Chu, 1999; US EPA, 2002b). Another consideration when creating an IBI is to identify variables independent of the environmental stress gradient (e.g., elevation, landform type, wetland class) that may impact the distribution of biological communities (Karr and Chu, 1999; Rader, 2001). These covariates can be used to define the reference condition more narrowly, allowing greater sensitivity to the signal of disturbance against the background noise of natural variability among ecosystems.

IBIs are a multi-metric bioassessment tool, but are not the only tool available for ecosystem condition assessments. Multivariate techniques are also widely used and have some advantages over multi-metric tools. Multivariate approaches use reference sites to create a predictive model based on community composition, comparing the observed community at a test site to the expected community derived from reference conditions (Bonada et al., 2006; Gerritsen, 1995; Reynoldson et al., 1997). Multivariate approaches make no *a priori* assumptions about relationships of biological communities with disturbance, and reference sites are grouped objectively based on community assemblages (Bonada et al., 2006; Reynoldson et al., 1997). Multi-metric indices condense complex ecological data into a few metrics and a major critique of this approach is the potential for compounding error through the incorporation of redundant metrics (Reynoldson et al., 1997). Yet, multivariate approaches are more complex, require specialized practitioners, and the results are difficult to convey to the public (Gerritsen, 1995). Further, the *a priori* assumptions inherent to the multi-metric approach can be viewed as theory-based hypotheses about how assessed ecosystems function, whereas multivariate approaches could be critiqued as data-mining expeditions prone to overfitting. Multi-metric tools have been shown to have similar consistency and repeatability as multivariate tools (Stribling et al., 2008), and where both approaches have been applied to the same set of sites, results are in agreement (Herbst and Silldorff, 2006), suggesting that the choice between techniques is inconsequential. The multi-metric tools are sometimes argued to be more useful for resource managers, providing diagnostic information in the form of component metrics that can offer mechanisms to explain the ecological effects of anthropogenic degradation (Bonada et al., 2006).

In the last two decades, IBIs have been applied to wetlands, with the United States Environmental Protection Agency (US EPA) publishing a suite of documents to standardize and outline the methodology for creating regional IBIs (US EPA, 2002b). Multi-metric indices, like IBIs, are being incorporated into government environmental management structures due to their ability to summarize and convey complex ecological data in a relatively easy to understand manner (Stevenson, 2001). In Alberta, IBIs have been embraced as a tool for the certification of reclaimed wetlands in the Oil Sands Region (Alberta Environment and Sustainable Resource Development, 2013). Similarly, the Alberta Wetland Policy Team is seeking to adopt an IBI to monitor the integrity of restored wetlands as a component of compliance monitoring under the Wetland Policy's compensation regulations.

1.4.1.1 Bird Indicators

Birds make excellent bioindicators because they are not only sensitive to human activities, but are valued highly in society and bird surveys are relatively low-cost and not overly complicated to conduct (US EPA, 2002a; Wilson and Bayley, 2012). Wildlife habitat is one of most highly valued functions provided by the PPR, specifically for avian species. Due to the importance of wetlands in the PPR for waterbirds, there is great potential for the use of birds as an indicator of wetland integrity in this region. The term waterbirds encompasses waterfowl, shorebirds, and wetland dependent songbirds. Previous research has shown that metrics derived from wetland dependant songbird communities have a strong relationship with a stress gradient in the Parkland natural region in Alberta (Wilson and Bayley, 2012). Waterbird communities have not been used widely as source of biological metrics for IBIs, but there is support for these to be used as an indicator of environmental integrity (Bryce, 2006; Tangen et al., 2003; Wilson and Bayley, 2012; Wray and Bayley, 2006). Due to their increased mobility and larger home range compared to other biological indicators such as, benthic macro-invertebrates, amphibians, vegetation, birds can be responsive to changes in the surrounding landscape that are not be immediately evident in less mobile populations (Rooney et al., 2012; US EPA, 2002b). Based on their ease of sampling, response to different spatial scales, sensitivity to a stress gradient, and societal value, there is great but unexplored potential to use waterbirds as biological indictors within an IBI.

1.5 Thesis Organization

The goals of my thesis were to: 1) develop indices of biological integrity (IBI) from the avian community for the PPR in Alberta, and 2) evaluate wetland restoration outcomes using the avian community. The following two chapters are written as manuscripts to be submitted to the appropriate journals for publication. In Chapter 2, using metrics from the avian community, I developed IBIs for both the Grassland and Parkland regions of Alberta and investigated if an IBI for both regions could be appropriate. In Chapter 3, also using avian community composition, I explored restoration outcomes of wetlands spanning a range in permanence classes that were all restored using ditch plugs. I compared natural wetlands along a gradient of agricultural disturbance to restored wetlands in the Parkland region to determine if degradation results in a gradient of avifaunal change based on a space for time substitution and to determine if restored wetlands are returning to a reference state. In Chapter 4, I synthesize my two data chapters, applying my Parkland IBI to evaluate the condition of restored wetlands in the Parkland. I also discuss the application of my two data chapters to wetland policy implementation in Alberta. Through assessing wetland restoration efforts in the Parkland region of Alberta, I hope to inform the Government of Alberta on the state of restoration projects in the province and help guide future restoration practices in the prairies.

2 Development of bird-based indices of biological integrity to monitor wetland condition in marshes in Alberta, Canada

2.1 Introduction

To fulfil the ‘no net loss’ objective of most North American wetland policies, mitigation hierarchies are often employed to compensate for wetland losses through wetland creation or restoration. Wetland compensation efforts may balance losses based on area, but there is mounting evidence that mitigation wetlands are not functionally or structurally equivalent to natural reference wetlands (e.g., Gebo and Brooks, 2012; Moreno-Mateos et al., 2012; Stefanik and Mitsch, 2012; Whigham, 1999). Stemming from this evidence are recommendations for the use of measureable and enforceable standards in the design and construction of mitigation wetlands projects to improve their success (Brooks and Gebo, 2013). In Canada, wetland conservation is under the jurisdiction of the provinces and varies considerably among them (Rubec and Hanson, 2009). Recent updates to the Alberta wetland policy have incorporated a mitigation hierarchy, which is a conservation framework that prioritizes the avoidance of wetland loss, and, where losses are considered unavoidable, it outlines compensation provisions through wetland restoration (Goverment of Alberta, 2013). Further guidance on implementation and evaluation of wetland restoration success is lacking, highlighting the need for tools to assess mitigation wetlands in the province to protect against the loss of wetland functions that coincide with compensatory mitigation.

Bioassessment has been used widely in environmental management, and refers to using biological measurements to evaluate the level of human disturbance affecting the system under investigation (Rader, 2001). Bioassessment to evaluate restored wetlands could take multiple forms, from a rapid assessment checklist or questionnaire approach (e.g., Government of Alberta, 2015) to a more rigorous evaluation of biological integrity (e.g., Wilson et al., 2013). Biological integrity is inherent in highly functioning, minimally disturbed ecosystems that are '… able to support and maintain a balanced, integrated, and adaptive biological system having the full range of elements and processes expected for a region' (Karr and Chu, 1999). Thus, human disturbance impairs the biological integrity of aquatic ecosystems.

Karr (1981) was the first to develop an Index of Biological Integrity (IBI) to measure biological integrity directly, beginning with measurements of fish assemblages to evaluate streams and rivers. Since their inception, IBI's have been applied to a variety of aquatic ecosystems including wetlands (e.g., Hartzell et al., 2007; Noson and Hutto, 2005; Wilson et al., 2013), using a variety of biological assemblages such as birds (e.g., Bryce et al., 2002), vegetation (e.g., DeKeyser et al., 2003), and invertebrates (e.g., Helgen and Gernes, 2001). IBIs are multi-metric diagnostic tools, where metrics respond predictably to a gradient of human disturbance (Karr and Chu, 1999). Metrics may be based on a range of attributes, including life history characteristics, functional traits, and/or community composition of the taxon or assemblage of interest.

By measuring metric values in relatively pristine reference sites, where no source of human disturbance is evident, as well as in sites where human disturbance is obvious, IBI scores can be calibrated to a particular region and disturbance type. IBIs cannot be reliably extrapolated outside the region where they were developed because geographic gradients in soil type, climate, and irradiance, as well as regional shifts in species pools will alter the character of relatively pristine sites in a manner that is independent of any human disturbance (Karr and Chu, 1999). Thus, the reference condition characterized in one area may not be appropriate in another.

Similarly, if the region being characterized is so large that natural gradients within it give rise to alternative reference states, averaging across those gradients will mean that the reference condition is not precisely defined. Because IBIs function by comparing conditions at a test site to the range of natural variability encompassed by the reference condition, an imprecisely defined reference condition will result in a low power to detect deviations attributable to human disturbance. A more narrowly defined reference condition will create a more sensitive IBI, and IBIs are thus specific to the region in where they are developed (Karr and Chu, 1999).

IBI's have been successfully validated for permanent wetlands across North America (Mack, 2007; Miller et al., 2006; Rooney and Bayley, 2012a; Wilson et al., 2013), although with limited success in temporary, seasonal, and semi-permanent marshes (Euliss and Mushet, 2011; Tangen et al., 2003). This is problematic because these small, temporary to semi-permanent marshes are also the most abundant wetlands in the Prairie Pothole Region (PPR) (e.g., Serran and Creed, 2016), which comprises 23.4 % of Alberta's land area (Downing and Pettapiece, 2006). The PPR is characterized by the extensive distribution of small marshes with variable hydroperiods (Wray and Bayley, 2006).

The PPR is a region with a high conservation priority because of its important ecological function as habitat for wildlife, specifically waterfowl (Beyersbergen et al., 2004). Wetlands have been greatly affected in this region by agriculture: drainage of marshes has been historically high and continues (Gleason et al., 2008). To compensate for these losses under the new Alberta Wetland Policy, an increase in mitigation projects is anticipated in the PPR.

Difficulties in developing IBIs for use in temporary to semi-permanent marshes is attributed to natural fluctuations in water depth in these marshes that complicate assessments of plants, fish, and invertebrates (Euliss and Mushet, 2011; Tangen et al., 2003; Wilcox et al., 2002). Waterbirds (i.e., wetland obligate and facultative passerines and waterfowl), however, have been recommended as a possible bioindicator taxon in temporary to semi-permanent marshes (Tangen et al., 2003). Bird assemblages are considered good candidate indicators for use in IBIs because of the ease of sampling and the widely documented effects of habitat disturbances on bird community dynamics (Chin et al., 2015). Birds have wide societal appreciation and are highly valued ecosystem components, often driving conservation objectives and the call for further management (Weller, 1999). The mobility of bird species incorporates the landscape scale into condition assessments (e.g., Rooney et al., 2012) and having multiple spatial scales of influence represented in an IBI addresses the multifaceted effects of different stressors acting within a system (Veselka et al., 2010). Furthermore, wetland dependent passerines have already been demonstrated to be effective indicators of the integrity of permanent marshes in the Parkland natural region in Alberta (Wilson and Bayley, 2012). They are thus likely candidates to exhibit a strong, predictable relationship to human disturbance across Alberta's PPR.

I aimed to develop and validate an IBI based on metrics calculated from the avian assemblage at temporary to semi-permanent marshes that could indicate the level of agricultural disturbance in the northern extent of the PPR region in Alberta, Canada. The PPR region in Alberta is comprised of two natural regions, the Parkland and Grassland, which are managed jointly as a single unit. For management purposes, having larger jurisdictions and universal tools can improve the efficiency of natural resource management. Yet, the range of natural variability within each of the Parkland and Grassland regions may differ, such that combining these regions could yield a reference condition too broad to generate a sensitive IBI, where managers are thus incapable of detecting biological impairment. To produce a sensitive IBI, it may be necessary to stratify by natural region and accept different metrics related to the distinct species pools and ecological relationships unique to each natural region. Consequently, I also tested whether a single IBI could be used to monitor wetland condition in both regions with the same metrics, or whether the detection of agricultural disturbance in non-permanent marshes of the Grassland and Parkland is improved by using region-specific IBIs.

2.2 Methods

2.2.1 Study Area

The northern extent of the Prairie Pothole Region (PPR) in Alberta is composed of the Parkland and Grassland natural regions. Both the Parkland and Grassland regions fit within the larger Great Plains ecoregion of North America, which has undulating topography underlain with glacial deposits that create a landscape characterized by an abundance of non-permanent wetlands (Commission for Environmental Cooperation, 1997; Downing and Pettapiece, 2006). These regions are defined by warm temperatures and a dry climate. The Parkland has sufficient moisture to support aspen forests (mean annual precipitation = 447 mm and mean annual temperature = 2.3°C), however, in the Grassland, trees are severely limited by the combination of lower rainfall (mean annual precipitation = 370 mm) and higher temperatures (mean annual temperature = 3.9°C) (Schneider, 2013).

I confined my study area to six sub-watersheds within the PPR in Alberta, three in each of the Parkland and Grassland regions (*Figure 2-1*). The six sub-watersheds were chosen based on the following criteria: (1) contained entirely within a single natural region, (2) contained entirely within Alberta, and (3) comprising post-glacial landforms dominated by poorly sorted moraine deposits. I chose these geographic regions to minimize differences in physical, chemical and biological parameters within each region (Karr and Chu, 1999; US EPA, 2002c).

2.2.2 Wetland Selection and Sampling Design

I selected wetlands randomly from a pool of all non-permanent wetlands in the study region, stratified by size and wetland class using the provincial Alberta Merged Wetland Inventory (Alberta Environment and Parks, 2014) and Grassland Vegetation Inventory (Alberta Environment and Parks, 2011). The non-permanent wetland classes from the inventory included seasonal, temporary, and semi-permanent marshes, which correspond to the permanence classifications from Stewart and Kantrud (1971) of Class II (Temporary Pond), Class III (Seasonal Pond), Class IV (Semi-permanent Pond), respectively. The hydroperiod of these wetlands ranged from being wet for only a few weeks (Class II) to maintaining surface water throughout the growing season except in years of drought (Class IV). To ensure sampled wetlands spanned the entire gradient of agricultural disturbance, I assigned each wetland delineated in the wetland inventory and contained within my selected sub-watersheds to a disturbance bin based on the proportion of non-natural (i.e., crop, pasture, and built-up features) land cover within a 500 m radius buffer, derived from the Annual Crop Inventory Data (AAFC, 2015) and Grassland Vegetation Inventory (Alberta Environment and Parks, 2011). I classified wetlands into three disturbance bins: low (<25% non-natural cover within the buffer), medium (25- 75%), and high (>75%). Within each sub-watershed, I then randomly selected wetlands from within each disturbance bin, such that not only did the sample span a gradient in agricultural disturbance, but also an orthogonal gradient in wetland permanence class. I intentionally weighted the sample to include more low and high disturbance sites, to ensure the end-members of the disturbance gradient were well characterized. A perfectly even balance of sites was not accomplished due to constraints based on land access and inaccuracies in the remotely sensed wetland inventory.

I visited a total of 72 wetlands between 2014 and 2015. In 2014, I visited 18 wetlands in each of the Parkland and Grassland regions, six per sub-watershed. In 2015, an additional 18 wetlands, nine per natural region, were added to my study to supplement and improve the balance of sites sampled from the disturbance bins and permanence classes in 2014. *Table 2-1* outlines the distribution of wetlands sampled by disturbance bin and permanence class from all years, with further details for each site in Appendix 1.

2.2.3 Avian Surveys

I surveyed bird communities twice during the peak breeding season, with survey dates spanning from 19 May to 25 June, in both 2014 and 2015. Both a visual survey and auditory point count were conducted to capture different groups of wetland associated birds, including waterfowl, passerines, and wading birds (waterbirds, herein). I started with a 10 minute visual survey, from a position where all of the open water could be seen using a spotting scope and binoculars. Following the visual survey, I conducted an eight minute, 100 m fixed-radius auditory point count at a central point count location to target wetland dependent songbirds and other secretive waterbirds. Bird species and abundance were recorded according to the American Ornithologists Union standards (American Ornithologists' Union, 1983). Species counts were summed between the visual and auditory surveys for each site visit with care to not double count visual observations in the auditory survey. Surveys occurred between a half an hour before sunrise and six hours after sunrise. I classified wind and background noise according to standardized protocols (ABMI, 2012; US EPA, 2002a). Surveys were postponed (due to expected lower detections of waterbirds) in adverse conditions when wind and/or rain would inhibit detection of individuals. The bird counts from both survey dates were summed and used in analysis to ensure that both early and late breeding species were incorporated. Due to the small size (<1 ha) of most non-permanent marshes surveyed, I rarely had more than one point count location per wetland. At larger wetlands, auditory point count locations were positioned at a separation distance of 200 m, and enough point counts were surveyed to capture the entire wetland (US EPA, 2002a). I summed bird counts at sites with more than one auditory point count location. During auditory surveys, I made audio recordings with a Zoom MP3 recorder to document unknown calls that were subsequently identified with the assistance of audio imaging software, Audacity® V.2.1.0 (Audacity Team, 2014).

2.2.4 Indices of Biological Integrity

To determine if separate IBIs were needed for the Parkland and Grassland regions, I created three IBIs based on isolated evaluations for the Parkland (Parkland IBI) and Grassland (Grassland IBI) regions, and for the two natural regions combined (Both Regions IBI). My approach to developing the IBIs builds on Karr (1981)'s classic method with a few innovations, including the evaluation of metrics using the Spearman rank correlation coefficient between metric values and disturbance scores, redundancy analysis based on collinearity in the residuals from these Spearman rank correlations, and validation of the final IBI with an independent dataset (*Figure 2-2*). IBIs comprise metrics that represent hypotheses about how disturbance will influence biological communities (Miller et al., 2006). Metrics found to be sensitive to disturbance are standardized and scored before being summed to generate the IBI score. To validate the IBI, I partitioned my data into two representative sets: one for IBI development (24 sites per region) and one for validation (12 sites per region). This was achieved by ordering the sites in terms of their disturbance scores, breaking them into sets of three, and then randomly selecting one out of every three sites for inclusion in the validation dataset.

2.2.4.1 Preliminary site ranking

IBI development requires an objective basis for ranking wetlands from least to most disturbed condition. Previous studies have employed a wide range of methods to rank sites, including professional judgement (DeKeyser et al., 2003), surrounding land cover composition (DeLuca et al., 2004; Miller et al., 2006), environmental stressors (Rooney and Bayley, 2010), and rapid assessment methods (Mack, 2007; Veselka et al., 2010). I ranked sites using a disturbance index that I developed. The disturbance index was based on the proportion of non-natural land cover within a 500 m radius around each wetland from the AAFC crop inventory and Grassland Vegetation Inventory (AAFC, 2015; Alberta Environment and Parks, 2011), and was modified by field collected data that included: the degree of cattle grazing activity, the presence of pesticide residues in wetland soils, and presence of agricultural activity within the delineated wetland boundary (described in Appendix 2, data in Appendix 3). I used a 500 m buffer width because prior research in the Beaverhills sub-watershed of the Parkland region revealed that a bird-based IBI for permanent marshes was most strongly correlated with surrounding land use at this spatial scale (Rooney et al., 2012).

2.2.4.2 Metric Identification

I created an exhaustive collection of bird community metrics from the bird abundance data collected in 2014 and 2015 (Appendix 4). Metrics included functional traits (e.g., feeding habit, nesting habit, diet, migratory status, etc.), community structure characteristics (e.g., diversity, richness, etc.), and species-specific metrics (e.g., relative abundance of red-winged blackbirds (*Agelaius phoeniceus*)). I derived functional trait metrics from the abundance data, with species assigned to traits based on previous studies (Croonquist and Brooks, 1991; De Graaf et al., 1985; O'Connell et al., 1998; Veselka et al., 2010) and natural history information

(DeGraaf et al., 1991; Ehrilich et al., 1988). I created several metrics based on groups of species that were indicators of low or high disturbance for the different natural regions as outlined in relevant research from my study area (Polan, 2016). Only untransformed data were used for the calculation of candidate metrics. For all the metrics that involved more than one species (e.g., trait based metrics), different calculations were used to create four metric variations: total abundance (number of individuals), relative abundance (number of individuals/total individuals), richness (number of species), and proportion (number of individuals/number of species). Only the metric calculation method with the greatest correlation (r_s) with disturbance scores was selected for inclusion in the next phase of IBI development – redundancy analysis.

2.2.4.3 Metric Sensitivity

I evaluated metrics using graphical techniques, and descriptive statistics in R 3.2.5 (R Core Team, 2016). I evaluated the sensitivity of metrics to disturbance, calculating Spearman's ranking correlation coefficient (r_s) between my disturbance scores and raw values for each metric. This non-parametric test does not require transformation to meet assumptions of normality and permits assessment of non-linear relationships between the metrics and the disturbance scores that may more accurately reflect the nature of ecological relationships. I retained metrics that had ranking coefficients (r_s) greater then +/- 0.28 ($p < 0.05$) for further evaluation. Metrics considered in the next step, redundancy analysis, were both strongly and significantly related to disturbance (Mack, 2007).

2.2.4.4 Redundancy Analysis

Generally, it is undesirable to included redundant metrics in an IBI; those which provide collinear data. An IBI could compound measurement errors by including collinear metrics that are multiple measurements of the same basic biological factor. For example, both species richness and the Shannon-Wiener diversity index could be sensitive to disturbance, but if both were included in an IBI, any species detection errors of omission or commission would be counted twice. In nearly all published wetland IBI studies, redundancy is evaluated by ensuring that metrics included in the IBI are not strongly correlated with one another (Pearson or Spearman correlation coefficient < 0.6 to 0.9) (Bryce, 2006; Bryce et al., 2002; Chin et al., 2014; Collier, 2009; Genet and Bourdaghs, 2006; Lougheed et al., 2007; Miller et al., 2006; Rooney and Bayley, 2012; Veselka et al., 2010; Whittier et al., 2007; Wilson and Bayley, 2012). Unfortunately, this approach risks excluding metrics unnecessarily, as any two metrics that were highly sensitive to disturbance would naturally appear correlated along a disturbance gradient, given they are being calculated using data from the same sample of wetlands. An innovation in my IBI creation approach is that rather than evaluating redundancy in the form of correlation between metric values, I evaluated redundancy in terms of correlation between the residuals from the ranked differences between the metric values and the disturbance index scores for each site. Evaluating the redundancy of residuals has not yet been used to create an IBI based on my review of literature. Thus, I was able to focus explicitly on preventing the IBI from including metrics that could compound measurement error without risking the exclusion of metrics that were highly sensitive to disturbance. I selected metrics that had residuals that were not collinear, (Pearson r (r_p) <0.9: Appendix 6, 8, 10), based on the redundancy threshold set for other bird IBIs using Pearson correlation coefficients (Bryce et al., 2002). Among groups of metrics that were deemed redundant, I chose the metric with the strongest relationship (r_s) with the disturbance index. Eliminating metrics with highly correlated residuals decreases the potential of compounding errors when combining multiple metrics in the final index.

2.2.4.5 IBI Development, Testing and Validation

Before incorporating the final metrics into the IBIs, I inversed the metrics that were positively correlated with the disturbance index to maintain a consistent response when summing the individual metrics. I used a continuous whole range scoring approach to score the metrics (Bryce et al., 2002; Reiss, 2006; Rooney and Bayley, 2011; Whittier et al., 2007), which involved standardizing the metrics by dividing the metric value by its range and then multiplying by 10. I assembled IBI scores for each wetland by summing the scores from each of the included metrics.

I used simple linear regression to test the relationship of the IBI scores with the disturbance scores for the three different IBI tools: Parkland IBI, Grassland IBI, and combined Both Regions IBI. To validate the IBIs developed with the development datasets, I calculated the IBI scores for each of the wetlands in the validation dataset and used linear regression to evaluate the strength of the relationship between the three created IBIs and the disturbance index scores, calculated from this independent set of wetlands. To further evaluate the Both Region IBI for the combined regions, I used linear regression separately for the Parkland and Grassland sites to determine if the IBI had similar relationships when both regions were isolated.

2.3 Results

2.3.1 Summary Statistics

At the 72 wetlands visited over 2014 and 2015, 2097 individual birds were identified from 91 species. Forty-five of these species are considered wetland obligates or facultative wetland species. Species richness ranged from 5 to 17 for all of the wetlands visited and the number of individuals ranged from 8 to 80. The average species richness (± standard deviation) at wetlands by permanence class were: 10.5 ± 3.0 at Class IIs, 11.9 ± 3.0 at Class IIIs, and 12.5 ± 3.4 at Class

IV wetlands. The average species richness (± standard deviation) by the initial low, medium and high disturbance bins by land cover were: 11.5 ± 3.2 species, 11.7 ± 2.9 species, and 11.7 ± 3.4 species, respectively. In the Parkland region, a mean (± standard deviation) of 11.7 ± 3.3 species and 28.75 ± 12.3 individuals were identified at the study wetlands. In the Grassland region, a mean of 11.5 ± 3.1 species and 29.5 ± 14.9 individuals were observed.

2.3.2 Disturbance Scores

The calculated disturbance scores for the 72 wetlands ranged from 15 to 245, out of a total potential score of 250, with the highest scores indicating the greatest amount of agricultural disturbance (Appendix 3). In the Parkland region, the disturbance scores ranged from 13 to 245, with a mean (± standard deviation) of 136 ± 68.0. In the Grassland region, the scores ranged from 50 to 232, with a mean (± standard deviation) of 143 ± 44.0. Mean (± standard deviation) scores by permanence class for both regions were, 151.0 ± 50.0 for Class II wetlands, 127 ± 57.7 for Class IIIs, and 144.6 ± 62.8 for Class IV wetlands. The mean (± standard deviation) disturbances scores by the initial low, medium and high disturbance bins for both regions were: 98.8 ± 47.1, 134.6 ± 49.1, 184.5 ± 32.8, respectively.

2.3.3 IBI Development: Metrics Selection & Redundancy Analysis

In the Parkland region, the total number of metrics tested for a correlation with the disturbance scores was 394 (Appendix 5). Eighteen different metrics had an $r_s > |0.40|$ ($p < 0.05$) (*Table 2-2*). Six metrics remained after the redundancy analysis and were retained for the final Parkland IBI *(Table 2-3:* Appendix 6).

For the Grassland region, 345 metrics were tested for significant relationships with the disturbance scores (Appendix 7), of which 6 had a significant relationship (*Table 2-2*). Four metrics remained after the redundancy analysis for the final Grassland IBI (*Table 2-3;* Appendix 8).

For the IBI based on the amalgamation of both regions, a total of 420 metrics were investigated (Appendix 9), 14 had a significant relationship with the disturbance scores (*Table 2-2*). Three metrics remained after the redundancy analysis to create the final Both Regions IBI (*Table 2-3;* Appendix 10).

2.3.4 IBI Testing: Regressing IBI Scores on Disturbance Scores

The IBI score range was 0 - 60 for the Parkland region IBI, 0 - 40 for the Grassland IBI, and 0 – 30 for the Both Regions IBI. To confirm a consistent relationship between biological integrity (IBI score) and disturbance scores, I compared linear regression coefficients (r^2) between the development and validation datasets (*Table 2-4*).

For the Parkland IBI, the final IBI scores had a significant relationship with the disturbance scores for both the development ($r^2 = 0.50$; $p < 0.001$) and validation dataset ($r^2 = 0.75$, $p = 0.003$; *Figure 2-3*). For the Grassland IBI, the IBI scores had a significant relationship with the disturbance scores for the development dataset ($r^2 = 0.41$; $p < 0.001$), but not for the validation dataset ($r^2 = 0.02$; $p = 0.692$; *Figure 2-4*). For the Both Regions IBI, the IBI scores had a significant relationship with the disturbances scores for both the development dataset ($r^2 = 0.41$; $p < 0.001$) and the validation dataset ($r^2 = 0.39$; $p = 0.001$; *Figure 2-5*). When applying the Both Regions IBI separately to all Parkland sites, the IBI scores had a significant relationship with the disturbance scores ($r^2 = 0.54$; $p < 0.001$; *Figure 2-5*). When applying the Both Regions IBI separately to all Grassland sites, the IBI scores had a significant, but much weaker relationship with the disturbance scores ($r^2 = 0.12$; $p = 0.037$; *Figure 2-5*).

2.4 Discussion

My goal in this chapter was to investigate the ability of bird-based IBIs to reliably detect agricultural disturbance at temporary to semi-permanent marshes (Class II to Class IV) in the Parkland and Grassland regions of Alberta. Challenges for biotic assessment have been found in the PPR when using vegetation and benthic invertebrate communities (Tangen et al., 2003), presumably due to inter-annual variations in hydroperiod. With an increase in restoration activities expected in Alberta because of the recent adoption of a mitigation hierarchy under the new Alberta Wetland Policy (Goverment of Alberta, 2013), a tool is needed to evaluate the condition of mitigation projects and general wetland restoration success. Numerous authors have found that avian community metrics are sensitive to human disturbance (Bradford et al., 1998; DeLuca et al., 2004; O'Connell et al., 2000; Veselka et al., 2010), and my work in the Grassland and Parkland natural regions extends this finding to marshes of varying hydroperiod.

I successfully developed and validated an IBI for the Parkland region based on sensitive avian metrics. In the PPR, wetland selection by avian species is highly influenced by the composition of the surrounding landscape (Fairbairn and Dinsmore, 2001). At the highest integrity sites (25th percentile of IBI scores) in the Parkland, the average (± standard deviation) natural land cover around these sites was predominately shrubs and trees (48.25 % ± 26.57), whereas the lowest integrity sites (75th percentile of IBI scores) had predominately cultivated lands (72.28 % ± 27.11) within a 500 m radius around each wetland. The waterbird metrics were sensitive to this shift from a forested landscape to an agriculturally dominated landscape. For the Parkland IBI, most of metrics were indicators of specialist and generalist nesting and foraging traits, as observed in other avian bioassessment studies (O'Connell et al., 1998; Veselka et al., 2010).

In the Parkland region, metrics that were significant were specialist feeding and nesting functional traits that reflected the presence of forested landscapes, such as species richness of bark gleaners, relative abundance of foliage gleaning species, and species richness of shrub nesting birds. These traits were all negatively correlated with the disturbance scores, indicating the decline in shrubs and trees at lower integrity sites, not only in the surrounding landscape but also within wetlands themselves. The average amount of woody vegetation within the delineated wetland area in the highest integrity sites was 23.54 % ± 29.49, compared with 10.51 % ± 21.65 in the lowest integrity sites. The metrics that were positively correlated with disturbance scores reflected association of generalist species with lower integrity wetlands in more agriculturally-dominated landscapes. These metrics included indicator species that were more tolerant of human disturbance, such as the relative abundance of Green-winged Teals (*Anas crecca*) and the relative abundance of Vesper Sparrows (*Pooecetes gramineus*). Vesper Sparrow occurrence has been found to be higher at disturbed locations (Owens and Myres, 1973). Lastly, one of the metrics in the Parkland IBI was the relative abundance of species that prefer grassland habitat. This metric captures the land cover difference between higher and lower integrity sites, with lower integrity sites having more open, non-natural fields. The assemblage of species included in this metric that prefer grassland habitat included Horned Larks (*Eremophila alpestris*) and Savanah Sparrows (*Passerculus sandwichensis*), which often use agricultural fields (Ehrilich et al., 1988).

For the Grassland region, I successfully developed an IBI from waterbird metrics, and there were four metrics that were strongly correlated with the disturbance scores ($r_s > |0.4|$). These metrics characterized the change in condition from minimally impacted wetlands to highly disturbed wetlands in relation to local and landscape level habitat changes. For the Grassland sites, the land cover within the 500 m buffer at the highest integrity sites was predominantly grassland with an average of 70.91 % ± 35.98 cover, compared with the lowest integrity sites having predominantly agricultural land cover surrounding the sites, with an average of 38.88 % ± 36.76 cultivated land, and 18.86 % ± 14.30 pastureland. Consistent with the Parkland region, the Grassland region also had waterbird metrics indicative of generalist and specialist traits that were correlated with the disturbance scores. There was one metric included that was negatively correlated with the disturbances scores: the proportion of ground-nesting species. There was one species-specific metric, a habitat-generalist species, that was positively correlated with the disturbance scores, the relative abundance of Vesper Sparrows, a species that has been found to be more associated with cultivated lands (Owens and Myres, 1973). This metric reflects the impact of agricultural disturbance on wetland conditions, with increased cultivation driving out ground-nesting specialists, and habitat generalists increasing with more agricultural activity around the wetlands. The last two metrics included in the Grassland IBI were based on disturbance indicator species. These indicator species were categorized based on previous bird community analyses in my study region that identified species that were associated with low and highly disturbed grassland sites (Polan, 2016). The species grouped within the metric for low-disturbance indicators were Baird's Sparrow (*Ammodramus bairdii*), Northern Pintail (*Anas acuta*), and Western Meadowlark (*Sturnella neglecta*). Baird’s Sparrows occupy grassland habitat with seasonal and semi-permanent wetlands (Sousa and McDonal, 1983), and have been found to nest less frequently in agricultural fields than native grassland (McMaster et al., 2005; Owens and Myres, 1973). Northern Pintails are an upland nesting waterfowl species (Ehrilich et al., 1988) and are associated with wetlands with more grassland cover in the surrounding landscape (Naugle et al., 2001). While Western Meadowlarks are more widespread in agriculturally impacted landscapes: they avoid cultivated areas for nesting (Owens and Myres, 1973), the most dominate land cover surrounding high disturbance Grassland study sites. The species grouped within the high-disturbance-indicators metric were Black-billed Magpie (*Pica hudsonia*), Red-winged Blackbird (*Agelaius phoeniceus*), and Mallard (*Anas platyrhynchos*): all species with flexible habitat requirements (Ehrilich et al., 1988; Murkin et al., 1997). This metric increased with disturbance scores, as these species benefit from agricultural disturbance.

While the Grassland IBI was successfully developed, when IBI scores were calculated on the independent validation dataset, they were not significantly correlated with disturbance scores. There are two reasons that an IBI could fail to be validated: 1) either the index was over-fit to the wetlands used to develop it, or 2) the validation dataset was not representative of the same range of conditions as the development dataset (Picard and Cook, 1984).

I believe the validation dataset was not representative of the range of disturbance scores due to its small size (n = 12) and potential land cover classification errors within the Agriculture and Agri-food Canada (AAFC) crop inventory database. The disturbance index, and through it the ranking of sites in terms of their disturbance level, is the foundation for defining the sensitivity of the avian community metrics and the overall ecological integrity scores (Chin et al., 2015). The disturbance index that I used to rank sites was based on the extent of agricultural and other human-modified land cover types surrounding each wetland, which I obtained from the AAFC crop inventory. Rather than base the estimates of disturbances solely on landscape composition, however, I modified the index values based on 1) evidence of cattle grazing and intensity, 2) the presence of pesticide residues in wetland soils, and 3) the presence of a protective buffer between the wetlands and adjoining agricultural activities. These modifications were important because remotely sensed data may fail to detect human disturbance. For example, in the Grassland region, 10 of the 36 wetlands I sampled were identified as having 0 % non-natural land cover within a 500 m radius buffer, but I found evidence of cattle disturbance at 9 of these 10 sites, supporting prior conclusions that the AAFC crop inventory more accurately represented the extent of cropping than the extent of grazing (Kraft, 2016). In many instances grazed lands were misclassified as native grassland. Native prairie grassland, in fact, is extremely scarce in Alberta, and mostly restricted to the southern extent of the Grassland which was not covered within my study watersheds (Gauthier and Wiken, 2003). Yet based on the AAFC crop inventory data the Grassland wetlands had an average (± standard deviation) of 53.29 % ± 40.11 native grassland cover surrounding them. I conclude from this that there were very few truly low disturbance sites in the Grassland compared with the Parkland. In the Parkland region, where the dominant natural land cover was forest or shrub lands, the remotely sensed data more accurately characterized the land cover conditions likely due to the obvious structural differences between the natural land covers (i.e., the presence of trees and shrubs) and the non-natural land covers (i.e., cropland, pastureland, roads, etc.). I believe that because the validation datasets were relatively small (only 12 sites per natural region) and because most low disturbance sites in the Grassland had evidence of grazing activity, which was not apparent from the AAFC data, the validation dataset for the Grassland underestimated the level of disturbance in the sites classified as low disturbance. Rather than concluding that the Grassland IBI model was over-fit to the 24 wetlands used to develop the index, I suspect that the Grassland validation dataset was not significantly correlated with the disturbance scores because errors in the land-cover dataset made a few outliers obscure any underlying relationship. I conclude that a larger sample size is needed to confirm whether the Grassland IBI is significantly predictive of wetland integrity or not. Alternatively, executing a cross-validation technique (e.g., k-fold) would help improve my confidence in the validation of the created IBIs. I consider a cross-validation like this outside the scope of my thesis, but recommend it for future research.

As my second objective for this chapter, I sought to test whether it was necessary to use different assessment tools for the two natural regions. This is pertinent because under the Alberta policy regime, the Parkland and Grassland are managed jointly as the "white zone." For management purposes, it would be simpler to have a single tool that could be applied across the entire jurisdiction, but differences in climate, soils, and surficial geology, as well as differences in the dominant natural and human land uses between regions could mean that characterizing a single reference condition across the white zone would encompass too much variability. Consequently, it could be difficult to detect deviations from this loosely defined reference condition that could be reliably attributed to the influence of agriculture. Therefore, in addition to creating bird-based IBIs for each of the Grassland and Parkland regions, I tested whether a single IBI could be developed using common metrics sensitive to agricultural disturbance in both natural regions.

I was able to successfully develop and validate an IBI that could be applied in the Grassland and the Parkland; however, through further examination it was determined that the Parkland sites were the strongest component of the relationship with the disturbance scores. This likely occurred because the two distinct regions have different reference conditions and are best represented through regionally specific metrics. Only one metric was shared among both region-specific IBIs and the Both Regions IBI: the relative abundance of Vesper Sparrows. Large distinctions between Grassland and Parkland habitats exist in the form of structural differences in the vegetation of these regions, with trees being more abundant in the Parkland region. For example, the average forest cover in the highest integrity Parkland wetlands was 48.25 % ±

26.57, in contrast with 4.87 % ± 6.37 in the highest integrity Grassland sites. Tied to the habitat differences, are differences in the functional traits of the avian communities, such as the absence of forest-related traits (e.g., foliage gleaners and tree nesting) in the Grassland region where there is little natural forest cover. The discriminatory power of the IBI is reduced when metrics that represent important structural components that define each region's reference conditions are excluded, as reflected in the Both Regions IBI only having three non-redundant metrics. Additionally, the metrics included in the Both Regions IBI were not as strongly correlated with the disturbances scores as the metrics in the region-specific IBIs, with all three metrics with $|r_S|$ <0.44 compared to two metrics $|r_S| > 0.44$ in each of the two region-specific IBIs. Consequently, an IBI created to predict the integrity of wetlands in both the Parkland and Grassland regions is severely limited in its accuracy and discriminatory ability.

2.5 Conclusions

There is a need for management tools to monitor changes in wetland condition, both for tracking deterioration due to disturbances and monitoring restoration progress. I have successfully developed two IBI tools based on avian communities that can enable the monitoring of wetland condition and the assessment of restoration success in temporary to semi-permanent marshes in the northern extent of the PPR within Alberta, where agricultural activity is the primary driver of wetland loss and degradation. My inability to validate the Grassland IBI highlights the issues around the accuracy of remotely sensed data and need for field assessments when evaluating wetland condition, as exclusive reliance on remotely sensed data can lead to serious misclassification of sites. I determined that region-specific IBIs for the Grassland and Parkland are more accurately able to predict wetland biological integrity compared to an IBI constructed for both regions combined. Due to the evident difference in the reference conditions between the Grassland and Parkland regions, isolated IBIs will provide important guidance in evaluating the success of restoration efforts and provide an opportunity to guide management of these ecologically important systems.

2.6 Figures

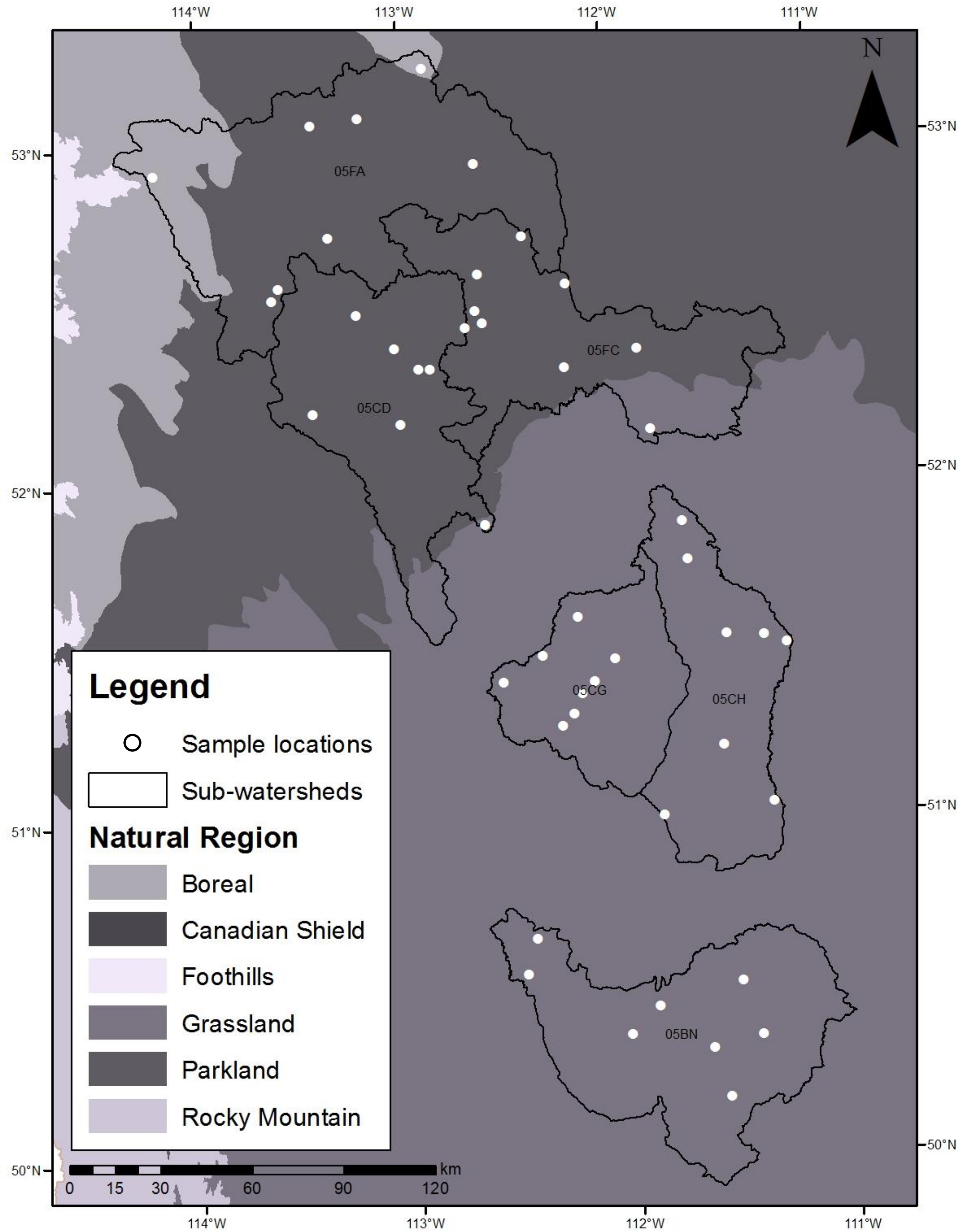

Figure 2-1. Map of sampling locations within the Parkland and Grassland Natural Region within Alberta, Canada. Number-letter codes are the names of sub-watersheds that were sampled.

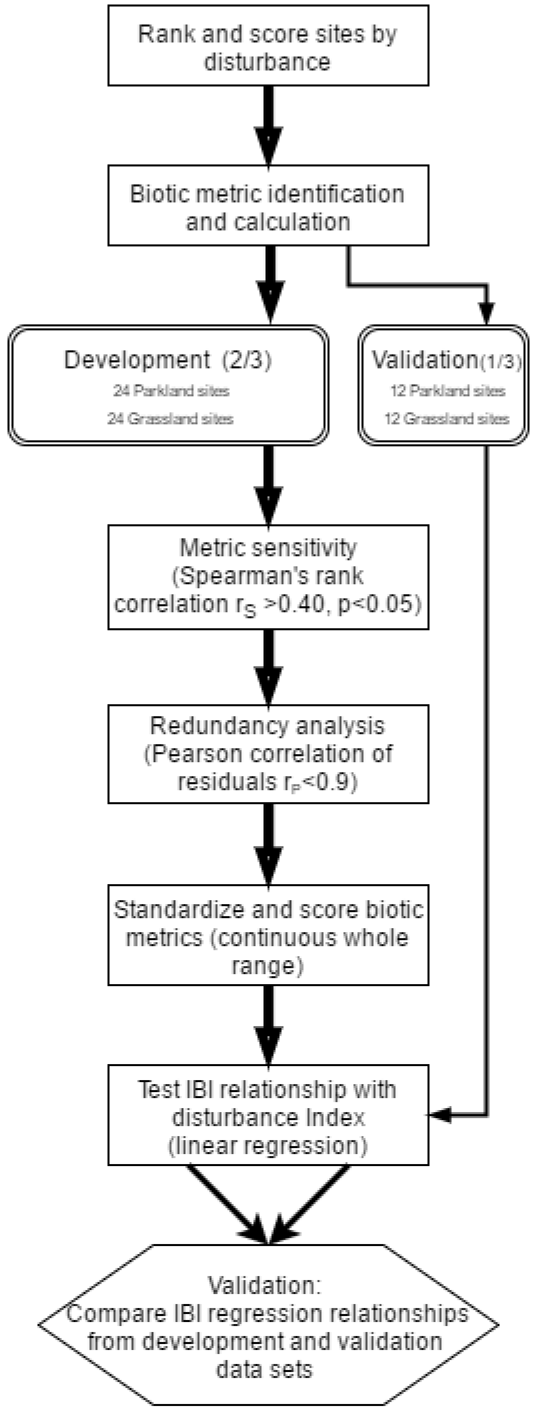

Figure 2-2. Schematic illustrating the steps in IBI development and validation.

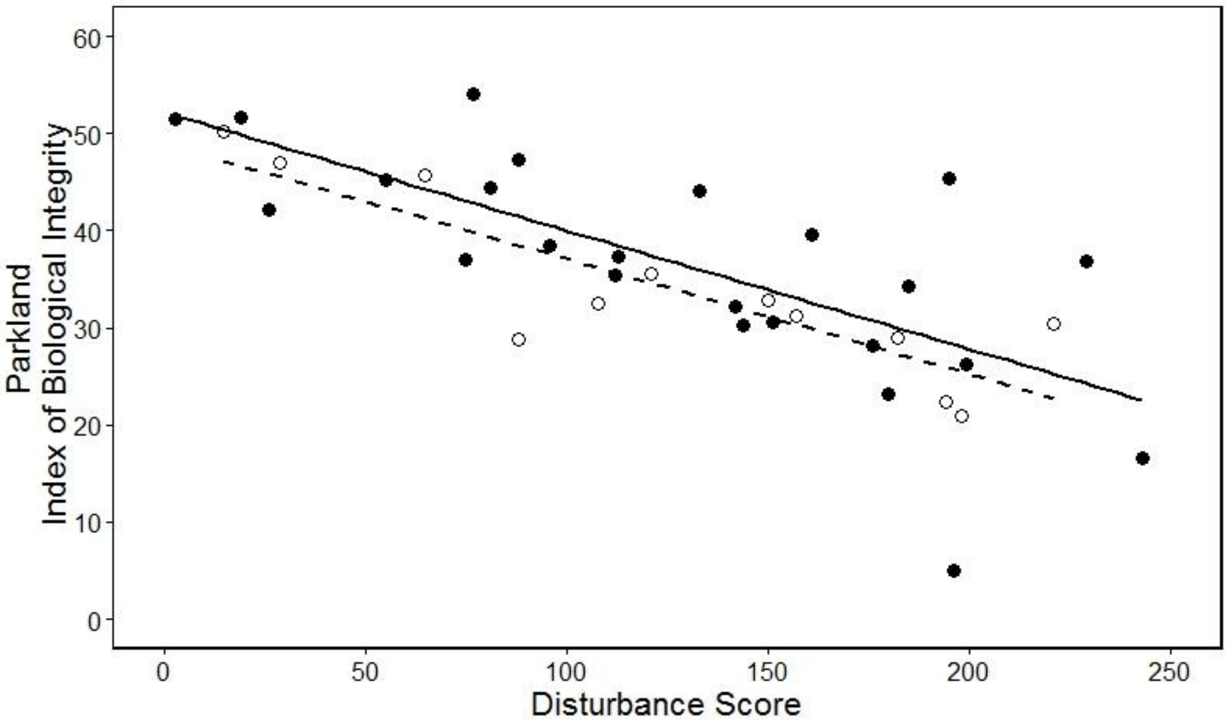

Figure 2-3. Parkland IBI scores for all sites plotted against the disturbance scores. Symbology reflects IBI development and validation datasets: development (n = 24; black circles); and validation (n = 12; white circles). Linear regression lines are drawn for development (solid line) and validation datasets (dashed line). Note that the Parkland IBI produced similar, significant linear regression relationships between IBI score and Disturbance score, for both the development and validation datasets.

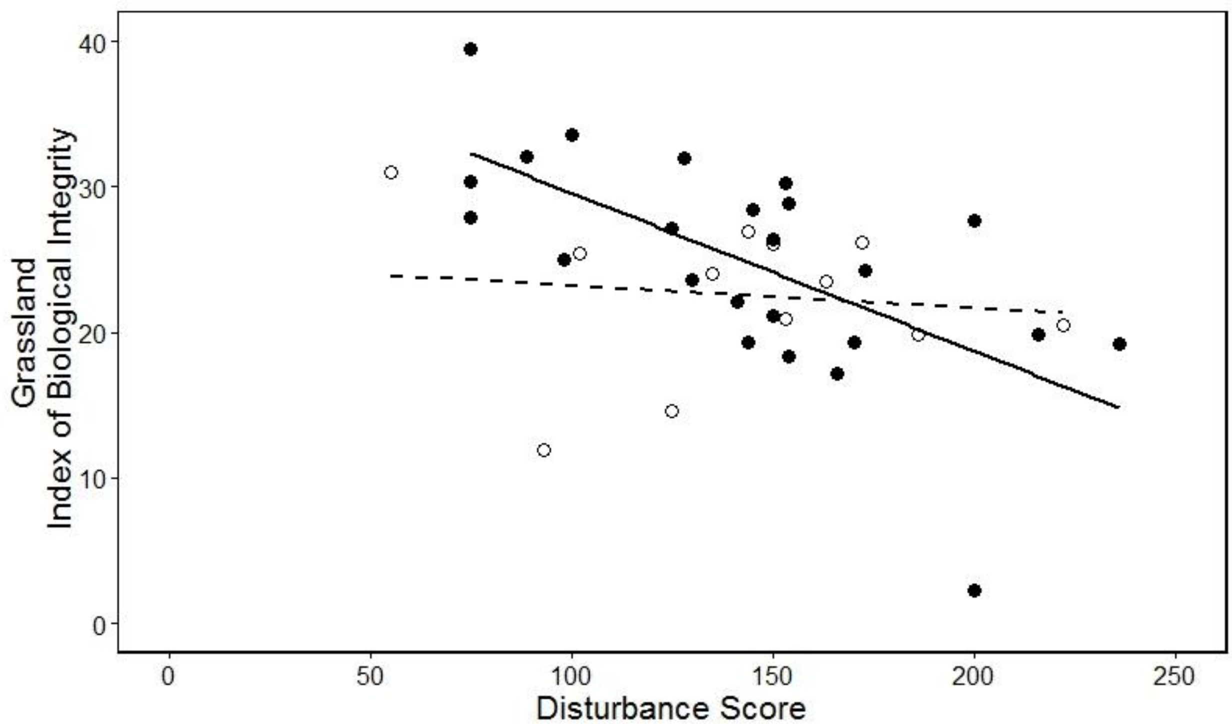

Figure 2-4. Grassland IBI scores for all sites plotted against the disturbance scores. Symbology reflects IBI development and validation datasets: development (n = 24; black circles); and validation (n = 12; white circles). Linear regression lines are drawn for development (solid line) and validation datasets (dashed line). Grassland IBI was successfully developed, and had a significant linear regression relationships found for the development dataset. However, no significant relationship was detected between IBI scores and Disturbance scores in the validation set. Note the unexpectedly low IBI scores for several of the wetlands with lower Disturbance scores. I attribute this discrepancy in the validation dataset to misclassification of grazed lands as native grassland, which would inflate the Disturbance scores for these sites.

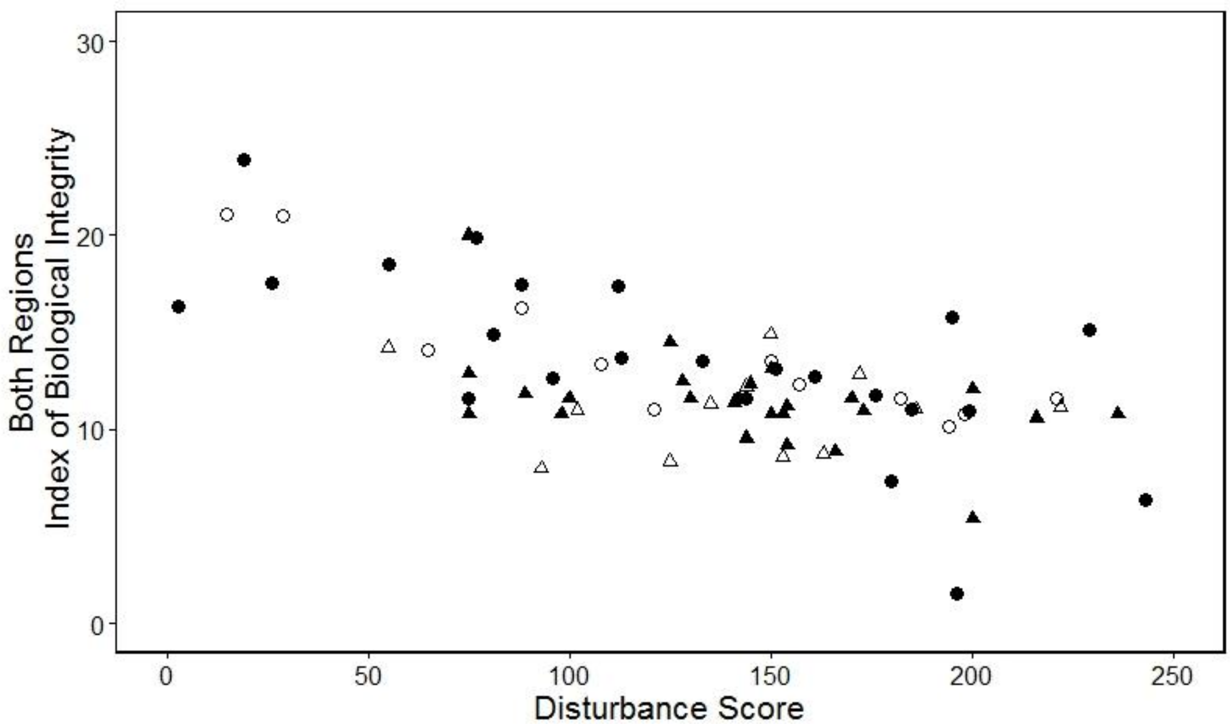

Figure 2-5. Both Regions IBI scores for all sites plotted against the Disturbance scores. Symbology reflects 1) natural regions: Parkland (circles (n = 36)); and Grassland (triangles (n = 36)), and 2) IBI development and validation datasets: development (n = 36; black shapes); and validation (n = 36; white shapes). The Both Regions IBI was successfully developed and validated, with similar significant linear regression relationships found for both the development and validation dataset. Note the absence of Grassland sites with Disturbance scores <50.

2.7 Tables

Table 2-1. Distribution of all 72 wetlands surveyed between 2014 and 2015, by disturbance bin and wetland permanence class for both the Parkland and Grassland regions.

	Disturbance Bin			Permanence Class		
	Low	**Medium**	**High**	**Class II**	**Class III**	**Class IV**
Parkland	10	8	18	11	12	13
Grassland	19	7	10	12	17	7

Table 2-2. Summary of the number of metrics tested for each IBI, with a breakdown of the number of metrics sensitive to the disturbance gradient ($|r_s|$ > 0.29), and the mean r_s and p-value of these significant metrics.

Region	**Total Metrics**	**# of Significant Metrics**	**Range r_S**	**Mean r_s**	**Range p**	**Mean p**
Parkland	394	18	0.41 – 0.71	0.50	0.0001 – 0.047	0.0126
Grassland	345	6	0.42 – 0.62	0.46	0.001 – 0.043	0.0273
Both Regions	420	14	0.29 – 0.45	0.37	0.001 – 0.049	0.0157

Table 2-3. Metrics selected for inclusion in the final IBIs for each region after redundancy analysis

Region	Metrics	rho (rs)	p-value
Parkland	Species richness of bark gleaning species (BrkGln_Sp)	-0.4309	0.0355
	Relative abundance of foliage gleaning species (FlgGln_RA)	-0.6868	0.0002
	Relative abundance of species that prefer grassland habitat (Grassland_Habitat_RA)	0.4350	0.0337
	Relative abundance of Green-winged Teals (GWTE_RA)	0.4160	0.0432
	Species richness of shrub nesting species (Shrb_Sp)	-0.4275	0.0372
	Relative abundance of Vesper Sparrows (VESP_RA)	0.4584	0.0243
Grassland	Relative abundance of high disturbance indicator species (Black-billed Magpie, Red-winged Blackbirds, Mallards) (BBMARWBLMALL_RA)	0.4250	0.0384
	Proportion of ground nesting species (Grnd_PR)	-0.6163	0.0013
	Richness of grassland low disturbance indicators (Baird's Sparrow, Northern Pintail, Western Meadowlark) (LowDis_Sp)	-0.5033	0.0122
	Total abundance of Vesper Sparrows (VESP)	0.4163	0.0430
Both Regions	Species richness of forest dwelling species (Forest_Sp)	-0.4450	0.0015
	Proportion of tropical migrant species (TrpclMgr_PR)	-0.2974	0.0401
	Relative abundance of Vesper Sparrows (VESP_RA)	0.4469	0.0015

Table 2-4. IBI development and validation by linear regression with disturbance scores for each region, with mean IBI scores, and the range of scores found.

Region	**Dataset**	**r^2**	**p**	**Mean IBI Score**	**IBI Score Range**
Parkland	Development	0.50	<0.001	36.6	5 – 54
	Validation	0.75	<0.001	33.9	21 – 50
Grassland	Development	0.42	<0.001	24.8	2 – 40
	Validation*	0.02	0.692	22.6	12 – 31
Both Regions	Development	0.41	<0.001	12.5	1 – 24
	Validation	0.40	0.001	12.5	8 – 21

* Note that the Grassland validation was not successful. I describe in the text how I believe that this was the results of misclassification of remotely identified land cover in the Grassland region in combination with the small sample size used in site validation (n = 12).

3 Deciphering the quacks: An assessment of wetland restoration success through comparison to natural wetlands in the Aspen Parkland Region of Alberta, Canada

3.1 Introduction

Wetland restoration has been legislated and integrated into wetland policies in the US and Canada as a way to offset wetland losses from human developments. In the wake of the 1971 Ramsar Convention on the conservation of wetlands, Canada initiated a federal policy on wetland conservation, which was then mirrored by provincial wetland policies in much of the country (Rubec and Hanson, 2009). These policies parallel the 'no net loss' policy of Section 404 of the Clean Water Act, implemented in 1977 in the United States, and require compensatory mitigation for unavoidable impacts to wetlands. Specifically, the new Alberta wetland policy (Goverment of Alberta, 2013) embraces the practice of mitigation banking. Under this practice, wetland creation, restoration, and enhancement are used to offset lost wetland functions in situations where the destruction of natural wetlands has been deemed unavoidable.

Mitigation banking hinges on the conceptual model that describes wetland degradation as reversible by restoration along a linear path (e.g., *Figure 3-1*). In ecosystem dynamics terms, the conceptual model most often assumed to operate in wetland mitigation banking is one of "gradual, continuous change" (Suding and Hobbs, 2009). This borrows from ecological succession theory (e.g., Brooks et al., 2005, Dobson et al., 1997), wherein a wetland is conceptualized as occupying a state at some position along a developmental path, but is able to transition to other states on this same path through either the natural process of succession or through human interventions. The state of a wetland could be defined in terms of abiotic conditions, community structure, or even ecological processes. For example, if defining state using waterbirds, the model predicts that the community composition of waterbirds in a wetland would change in a gradual, continuous manner as the wetland becomes degraded, and then would return in a gradual, continuous manner in response to restoration.

Wetland policies allow for mitigation banking as compensation based on the assumption that restoration can reinstate ecological integrity and function in degraded wetlands (Zedler and Callaway, 1999). Despite mounting evidence that restored wetlands are more similar to degraded natural wetlands than to least disturbed, reference natural wetlands (Brooks et al., 2005; Brooks and Gebo, 2013; Gebo and Brooks, 2012), and that ecological processes such as biogeochemical cycling in restored wetlands may take decades or longer to recover to pre-disturbance levels (e.g., Moreno-Mateos et al., 2012), restoration practitioners seek to establish restored wetlands that are similar to natural sites to provide at least partial compensation for the destruction of natural wetlands. Wetland compensation policy is behind current scientific understanding of restoration, and further exploration of restoration outcomes are needed to guide policy compensation objectives.

The ecological importance of the Prairie Pothole Region (PPR) for wildlife habitat has been widely recognized since the creation of the North American Waterfowl Management Plan (NAWMP) in 1986, with management efforts concentrated on wetland habitat accrual and restoration (US Department of the Interior and Environment Canada, 1986). The PPR is characterized by numerous wetlands, a consequence of glaciation that left a subtle, undulating landscape with small depressions filled with wetlands that range in size and ponded-water permanence (Galatowitsch and van der Valk, 1994). The biological communities and physical properties of these wetlands are naturally dynamic, but they have been greatly affected by agricultural expansion that has drained them or altered their hydrology (McCauley et al., 2015; Voldseth et al., 2007; Wiltermuth and Anteau, 2016). The small wetlands that are dominant on this landscape are very important breeding habitat for waterfowl (Batt et al., 1989; Naugle et al., 2001). A high number of wetland restoration projects have been undertaken in this region, largely implemented through Ducks Unlimited Canada (Gray et al., 1999), in response to high historical losses and continued drainage that has negatively affected waterfowl populations (Batt et al., 1989).

At the northern extent of the PPR, the Aspen Parkland natural region in Alberta has a high number of Ducks Unlimited Canada wetland restoration projects that have focused on temporary, seasonal, and semi-permanent wetland restoration to offset the loss of wetlands associated with permitted agricultural drainage and urban and suburban expansion (Clare and Creed, 2014). Wetland restoration of these particular marsh classes is complicated by the difficulty of their complex hydrologic variability, and restoring natural hydroperiods to drained wetlands in the PPR has proved challenging (O'Neal et al., 2008). An assessment of the compliance success of these compensatory restoration efforts in the Aspen Parkland is needed. Avian communities in non-permanent wetlands are a reliable indicator of wetland condition for non-permanent wetlands in the Parkland region (as discuss in Chapter 2; Wilson and Bayley, 2012), and generally for wetlands in the PPR (Dault, 2001; Veselka et al., 2010). With the broad mandate of Ducks Unlimited Canada to restored wetlands to ensure abundant waterfowl populations in the PPR (Ducks Unlimited Canada, n.d.), the use of avian species to assess restoration outcomes allows for these wetlands to be evaluated based on the set objectives for these restoration projects.

Monitoring restoration progress in these marshes can inform our understanding of natural succession and improve restoration practices (Brooks et al., 2005), especially where the aim is not simply to create more duck habitat but compensate for the loss of natural wetlands. I compared natural wetlands along a gradient in human disturbance, using a space for time substitution, to evaluate the change in avian community composition and diversity in response to anthropogenic disturbance. I sought to assess restoration outcomes in a mitigation context through exploring avian communities at wetlands restored through ditch-plugging and comparing these with avian communities in natural wetlands in the Aspen Parkland region.

3.2 Methods

3.2.1 Study Area

I confined my study area to three sub-watersheds within the Aspen Parkland natural region in central Alberta (*Figure 3-2*). These three sub-watersheds were chosen based on the following criteria. 1) They were contained entirely within the Parkland region to minimize among-region differences in physical, chemical and biological parameters that could introduce noise into an assessment of wetland condition (United States Environmental Protection Agency 2002b); 2) They were contained entirely within Alberta to ensure that provincial datasets could adequately cover the sub-watersheds; and, 3) The sub-watersheds consisted of post-glacial landforms dominated by poorly sorted moraine deposits to minimize differences in soils and wetland abundance among sub-watersheds.

3.2.2 Wetland Selection and Sampling

I visited a total of 60 wetlands between 2014 and 2015, 36 natural and 24 restored. I selected potential study sites from a pool of all non-permanent wetlands in the study region using the provincial Merged Wetland Inventory (Alberta Environment and Parks, 2014) and Grassland

Vegetation Inventory (Alberta Environment and Parks, 2014). The non-permanent wetland classes from the inventory included seasonal, temporary, and semi-permanent marshes, which correspond to the permanence classifications from Stewart and Kantrud (1971), Class II (temporary pond), Class III (seasonal pond), Class IV (semi-permanent pond), respectively. The hydroperiod of these wetlands ranged from being wet for only a few weeks (Class II) to maintaining surface water throughout the growing season except in years of drought (Class IV). I assigned all inventoried wetlands within the sub-watersheds to one of three disturbance bins based on the proportion of non-natural (i.e., crop, pasture, and built-up features) land cover within a 500 m radius buffer around it. Land use patterns around wetlands were used as a surrogate for anthropogenic disturbance (Brooks et al., 2004; O'Connell et al., 2000), and allowed for comparison to similar avian community evaluations (Begley et al., 2012; Puchniak, 2002). Land cover was derived from Agriculture Agri-Food Canada's (AAFC) Annual Crop Inventory Data (AAFC, 2015) and the Grassland Vegetation Inventory (Alberta Environment and Parks, 2011). Low-disturbance wetlands had < 25 % non-natural cover within the buffer, medium-disturbance wetlands had 25 - 75% non-natural cover, and high-disturbance wetlands had > 75 % non-natural cover. Within each sub-watershed, I then randomly selected wetlands from each disturbance bin, such that not only did they span a gradient in agricultural disturbance, but also an orthogonal gradient in wetland permanence class and size. An even balance of sites was not accomplished due to constraints based on land access and inaccuracies in the remotely sensed wetland inventory.

Table 3-1 outlines the distribution of wetlands sampled by disturbance bin and permanence class from all years. In 2014, I visited 18 wetlands, six per sub-watershed. In 2015, an additional 18 wetlands were added to my study to supplement and improve the balance of sites sampled from the different permanence classes. Further details on each site noted in Appendix 11.

I selected restored wetlands from among the Ducks Unlimited Canada (DU) restoration projects within the Parkland. I attempted to have all restored wetlands within the three sub-watersheds, but due to the limited supply of restored sites, two sites were selected within 2 km of the sub-watershed boundaries. All sites were restored by ditch plugs, engineered and constructed by DU staff between 2004 and 2013. When there was more than one restored wetland per project, I selected a study site with minimal drainage (favouring sites without a surface water outlet). Additionally, I strove to maintain a distribution of permanence classes and sizes that were representative of the candidate restored sites. I chose only one restored wetland per project unless there was more than 1 km separating study sites.

3.2.3 Avian Surveys

I surveyed bird communities twice during the peak breeding season, with survey dates spanning from 19 May to 25 June, in both 2014 and 2015. Both a visual survey and auditory point counts were conducted to capture different groups of wetland associated birds, including waterfowl, passerines, and wading birds. I started with a 10 minute visual survey, from a position where all of the open water could be seen using a spotting scope and binoculars. Following the visual survey, I conducted an eight minute, 100 m fixed-radius auditory point count at a central location to target wetland dependent songbirds and other secretive waterbirds. The abundance and identity of all bird species observed and heard were recorded according to the American Ornithologists Union standards (American Ornithologists' Union, 1983). Species counts were summed between the visual and auditory surveys for each site visit with care to not double count visual observations in the auditory survey. Surveys occurred between a half an hour before sunrise and six hours after sunrise, when weather conditions were acceptable. I classified wind and background noise according to standardized protocols (ABMI, 2012; US EPA, 2002a). Surveys were postponed due to lower detections of birds in adverse conditions, with moderate wind and/or rain. Due to the small size (< 1 ha) of most non-permanent wetlands surveyed, a single point count location per wetland was sufficient to characterize the entire wetland. At larger wetlands, auditory point count locations were positioned at a separation distance of 200 m, and enough point counts were surveyed to capture the entire wetland (US EPA, 2002a). I summed bird counts at larger sites with more than one auditory point count location, assuming that 200 m spacing between point count locations yielded non-overlapping counts from 100 m fixed-radius point counts. During auditory surveys, I made audio recordings with a Zoom MP3 recorder to document unknown calls that were subsequently identified with the assistance of audio imaging software, in Audacity® V.2.1.0 (Audacity Team, 2014).

3.2.4 Wetland Habitat Characteristics

To characterize local wetland habitat features, I collected additional information from each wetland. I classified each wetland according to Stewart and Kantrud (1971)'s major classes of natural ponds and lakes, based on the wetland vegetation zones and water permanence. I estimated permanence based on monthly measures of maximum water depth, using a staff gauge.

In July, wetland boundaries were delineated on the basis of vegetation and soil characteristics to determine total wetland area. I characterized the vegetation in each wetland using the proportional wetland area covered by distinct vegetation assemblages, characterized by growth form (ground cover, narrow-leaved emergent, broad-leaved emergent, robust emergent, woody vegetation, drawdown region, and open-water area) and the dominant or co-dominant plant species. These assemblages were delineated using a high-precision GPS with SX Blue II receiver (Geneq Inc.; Montreal, Quebec) with 2.5 m spatial resolution. This mapping provided the area of each vegetation assemblage within each wetland.

To characterize the landscape context for each wetland, I extracted land cover within a 500 m radius buffer encircling each wetland polygon, using ArcMap Version 10.3.1 (ESRI, 2015) on land cover data provided by AAFC's Annual Crop Inventory (AAFC, 2015) and the Grassland Vegetation Inventory (Alberta Environment and Parks, 2011). I used corresponding land cover data from the year each site was sampled.

3.2.5 Statistical Analyses

I performed all analyses using avian species abundance data, with counts summed across survey dates to ensure that both early- and late-breeding species were reflected in wetland-level surveys. All analyses were performed on the abundance data for all birds observed during surveys; however, some studies examining the success of wetland restoration for enhancing bird habitat have considered wetland obligate and facultative wetland bird species separately (e.g., Begley et al., 2012; Puchniak, 2002). I therefore repeated all analyses on using only wetland obligate and facultative wetland species (wetland-associated, herein) to help me assess the sensitivity of wetland evaluations that exclude other birds that might use wetlands opportunistically. Analyses for wetland-associated species were restricted to 57 wetlands (23 natural; 24 restored), as wetland-associated species were absent from three natural wetland sites, two low-disturbance wetlands, and one high-disturbance wetland. All species observed during the wetland avian surveys are noted in Appendix 13, which also details the species that were designated as wetland-associated species (wetland obligates and facultative wetland species) based on Brooks and Croonquist (1990), Ehrilich et al. (1988), and Smith and Chow-Fraser

(2010). I conducted all statistical analyses using the statistical platform R, Version 3.2.5 (R Core Team, 2016).

3.2.5.1 Abundance and species richness

To evaluate if avian total abundance (all species) and species richness were significantly different between restored and natural wetlands, I tested for a difference between the restored, low-disturbance, medium-disturbance, and high-disturbance wetland classes, using a one-way ANOVA with type III sum of squares. I visually assessed whether ANOVA assumptions of the normality of residuals and homogeneity of variance were upheld using plots of residual vs. fitted values. Additionally, I performed Levene's test to test for homogeneity of variance. I log transformed both richness and abundance data for ANOVA analyses on all species and the sub-set of wetland-associated species.

3.2.5.2 Wetland habitat characteristics

To evaluate if local and landscape habitat characteristics (e.g., forest within wetland (%), crop within 500 m buffer (%), etc.) were significantly different between restored and natural wetlands, I ran multiple one way ANOVAs with type III sums of squares. I visually assessed whether ANOVA assumptions of the normality of residuals and homogeneity of variance were upheld using plots of residual vs. fitted values. Additionally, I performed Levene's test to test for homogeneity of variance. I square-root transformed landscape habitat variables that were proportions to better mimic a normal distribution.

3.2.5.3 Community analyses

For all community composition analyses, I relativized species abundance data by the species' maximum abundance, to reduce the influence of uncommon or highly abundant birds. I excluded very rare species (found at less than three wetlands, i.e., < 5% of the sites) to reduce the scarcity of the dataset prior to community analyses, as recommended in McCune and Grace (2002). Pair-wise distance between sites was based on the Bray-Curtis measure commonly used for ecological abundance data (McCune and Grace, 2002). To evaluate if there was a significant difference in the community composition of restored wetlands and the three classes of natural wetlands, I tested for a difference between the four groups using a multi-response permutation procedure (MRPP) with the mrpp function in the vegan package version 2.3-3 within R (Oksanen et al., 2016). I conducted post-hoc, pair-wise comparison testing also with MRPP, to evaluate which wetland types differed significantly. I assessed the statistical significance of pair-wise comparisons using a Bonferroni corrected α.

To visualize trends in avian community composition among wetlands, I performed a non-metric multidimensional scaling (NDMS) using the metaMDS function from the vegan library (Oksanen et al., 2016). I determined the optimal number of dimensions in the final solution by running the iterative analysis with 1-6 dimensional configurations and contrasting final stress values from up to 200 random starting configurations. I overlaid species abundances as vectors that were correlated with the NMDS axes ($r^2 > 0.2$) on the ordination using the envfit function from the vegan package in R (Oksanen et al., 2016). To further explore the relationship between avian community composition and habitat variables, I also plotted vectors representing the local- and landscape-level habitat characteristics that were correlated ($r^2 > 0.2$) with the NMDS axes. Vectors were scaled by their correlation with the NMDS axes, longer vectors indicate a stronger correlation. Confidence ellipses (90%) were drawn around the wetland disturbance groups. I repeated these ordinations on a dissimilarity matrix considering only wetland-associated species.

To quantify and evaluate beta diversity, a measure of species turnover in samples or communities, I used Jost (2007) variation on calculating beta diversity that incorporates effective species numbers and additive partitioning of beta diversity. I calculated the Jost (2007) beta diversity of the avian communities in restored wetlands and the natural wetlands in the three disturbance groups using the H function in the vegetarian package in R to quantify effective species numbers (Charney and Record, 2012).

3.3 Results

3.3.1 Species Richness and Abundance

Between 2014 and 2015, I surveyed 36 natural wetlands and 24 restored wetlands, observing 2216 individual birds from 86 species (Appendix 13). Thirty-six of these species are considered wetland obligates or facultative wetland species (Brooks and Croonquist, 1990; Ehrilich et al., 1988; Smith and Chow-Fraser, 2010). At natural wetlands, I observed 1177 individuals from 77 species, compared with 1039 individuals from 58 species in restored wetlands. Although total abundance and richness were greater in the natural wetlands, the average total abundance and richness of birds' per-wetland were slightly greater in restored sites (*Table 3-2*; *Figure 3-3*). These differences, however, were not significant (species abundance ANOVA: $F_{3,56} = 1.51$, p = 0.222; species richness ANOVA: $F_{3,56} = 1.16$, p = 0.333).

When considering wetland-associated species separately, total abundance was significantly different among restored wetlands and natural wetlands in the three disturbance groups (ANOVA: $F_{3,53} = 3.13$, p = 0.033; *Figure 3-4*). The average total abundance of birds per-wetland was significantly higher in restored wetlands than low-disturbance natural wetlands, p = 0.041 *(Figure 3-4*). The total species richness of wetland-associated species per-wetland was not significantly different among wetland types, however (*Figure 3-4*; ANOVA: $F_{3,53} = 2.19$, p = 0.100).

3.3.2 Wetland Characteristics

Local and landscape level habitat characteristics are summarized in *Table 3-3*, and raw data in Appendix 12. Most differences in local habitat characteristics were not found to be significantly different, likely due to high variance and unequal group sizes. In general, restored wetlands tended to differ from natural wetlands regarding hydrological characteristics, and were more similar to high-disturbance, natural wetlands. For example, on average, restored wetlands had deeper minimum and maximum depths than all natural wetland groups. The date of wetland dry out, on average, (based on Julian Date Number) was later in the year than all natural wetlands. In terms of wetland area, both restored and high-disturbance natural sites had similar extents of open-water habitat, but low-disturbance, natural wetlands had less open water. In contrast, low-disturbance, natural wetlands had a greater proportion of woody vegetation cover, compared with high-disturbance and restored wetlands, but again these differences were not statistically significant at alpha = 0.05 (Table *3-4*).

The landscape characteristics for restored sites had a distinct combination of land uses in the 500 m surrounding the study wetlands. Restored wetlands were surrounded by a higher proportion of natural land covers (e.g., forest ($p = 0.009$) and wetland ($p = 0.008$), *Table 3-5*), compared with high-disturbance, natural wetlands. Yet, the proportion of agricultural land surrounding restored wetlands was more similar to levels surrounding medium-disturbance wetlands, and significantly higher than the levels of agricultural activity around low-disturbance wetlands (e.g., crop ($p = 0.001$) and pasture ($p < 0.001$), *Table 3-5*).

3.3.3 Avian Community Composition

Avian community composition differed significantly among the four site types (MRPP: $A = 0.05$, $p = 0.001$). Pairwise comparison tests revealed that avian community composition at restored wetlands was significantly different from all natural wetland disturbance site types after applying a Bonferroni corrected α (*Table 3-6*). When avian community composition was analyzed on only wetland-associated species, there was no significant difference between restored wetlands and natural wetlands from the three disturbance groups (MRPP: $A < 0.01$, $p = 0.187$).

For the avian community data, after 72 iterations, the optimal NMDS solution was three-dimensional (Procrustes: RMSE < 0.001, max residual = 0.003). The stress of the final solution was 0.199, within the margins considered acceptable for ordinations of ecological data (McCune and Grace, 2002). There was substantial overlap between high-disturbance and restored wetlands in ordination space, especially on the first and second axes (*Figure 3-5* and *Figure 3-6*). In contrast, the position of low-disturbance sites in ordination space was distinct (*Figure 3-5* and *Figure 3-6*). My interpretation of Axis 1 is that it primarily reflects the gradient in agricultural disturbance, with low disturbances sites with negatives scores and high disturbance sites with positive scores. Based on the birds species and habitat characteristics associated with Axis 2, this axis reflects the gradient in permanence class among the wetlands I sampled. Axis 3 reflects undetermined drivers in avian community composition, as the habitat characteristics associated with this axis are only weakly correlated *(Figure 3-5* and *Figure 3-6*).

The NMDS solution based exclusively on the wetland-associated avian community also had a three-dimensional solution after 112 iterations (Procrustes: RMSE= 0.002, max residual = 0.006). Again, the stress of the final solution was within the range of acceptability for ecological data, at 0.183 (McCune and Grace, 2002). Notably, the three natural wetland groups overlapped in ordination space (*Figure 3-7*), and did not show evidence for the same gradient in community composition across disturbance categories as was apparent when all birds were considered. As observed when all birds were considered, in this ordination the restored wetlands form a tighter cluster, nested within the larger ordination space occupied by natural wetlands.

Considering all surveyed birds, beta diversity of the avian community at restored sites was 0.777, which was lower than all the natural wetland groups. Beta diversity was 1.127 for low, 0.925 for medium, and 1.091 for high-disturbance, natural wetlands. Similarly, when only wetland-associated birds were considered, beta diversity was lower at restored wetlands (0.776), compared with natural wetlands (1.104, 1.251, and 1.121 for low, medium, and high-disturbance wetland groups, respectively).

3.4 Discussion

I sought to evaluate restoration outcomes in a mitigation context through exploring avian community composition at restored wetlands. I compared non-permanent natural wetlands along a gradient in agricultural activity using a space for time substitution to determine if restored wetlands are more similar to the least disturbed, natural wetlands and whether they are achieving restoration objectives set by provincial mitigation policy and restoration practitioners. If restoration is successful, the waterbird communities of restored wetlands should be more similar to those found in relatively pristine reference wetlands than those found in wetlands disturbed by agricultural activities. The expectation that restoration activities can effectively re-establish the ecological integrity and function of degraded wetlands is the basis of wetland compensation policy in Alberta (Government of Alberta, 2013) and throughout the Prairie Pothole Region (e.g., Section 404(B) of the Clean Water Act lays out Compensatory Mitigation Requirements that apply to wetlands in the USA). With anticipated increases in wetland mitigation projects, it is critical that we understand restoration outcomes through evaluating how restored wetlands compare to natural wetlands. My results are therefore relevant to future wetland mitigation decisions and restoration guidelines in Alberta and across the Prairie Pothole Region (PPR). In general, I found that agricultural disturbance results in a gradual, continuous change in bird community composition, when all birds are considered, using a space for time substitution. Low-disturbance and high-disturbance wetlands support distinct avian communities, creating opposing end members of a gradient, with medium-disturbance wetlands occupying an intermediate position along that gradient. However, when comparing avian communities at wetlands restored through ditch plugging and natural wetlands along a gradient in human disturbance, restored wetlands are distinct from those found in least disturbed natural wetlands.

Mounting evidence suggests that wetland restoration fails to restore the function and structure of natural wetlands (e.g., Zedler et al., 1999; Hoeltje and Cole, 2007; Moreno-Mateos et al., 2012; Jessop et al., 2015). However, most comparison studies have contrasted restored wetlands solely to reference condition wetlands, and have not compared restored sites with natural wetlands along a gradient in human disturbance. Restoration success should not be evaluated as a binary “pass” or “fail” system, as it is possible for restoration to at least partially reverse the degradation and alteration of communities incurred by human activities like agriculture. In fact, mitigation provisions are based on the theory that restoration will return a degraded wetland to natural conditions over time (Zedler and Callaway, 1999). Although it may take many years for wetland communities and ecological processes to recover following restoration actions, it should not discredit the value of restoration if restoration is able to confer some improvement in conditions. Comparing restored wetlands to natural wetlands along a gradient in agricultural disturbance, rather than only to reference wetlands, enables me to detect even partial success in re-establishing waterbird community composition.

Based on my results, restored non-permanent wetlands are not currently equivalent to least disturbed, natural wetlands. Alternative models of ecosystem dynamics propose that the recovery path may be different than that of degradation, following a threshold or even hysteresis (Suding et al., 2004; Suding and Hobbs, 2009). In a threshold model of recovery, the system is able to suddenly recover after a period of resistance, whereas in a hysteresis recovery model, the system is in a stable, alternative recovery state even if environmental conditions are similar to least disturbed conditions and the recovery path follows a different trajectory than the degradation path (Suding et al., 2004; Suding and Hobbs, 2009).

Some studies in the PPR have observed that restored wetlands support lower avian abundance and richness than natural wetlands (Begley et al., 2012; Delphey and Dinsmore, 1993), whereas other studies in this region have detected no difference in abundance and richness of the avian community (e.g., Ratti et al., 2001; Puchniak, 2002). My results generally agree with the latter group, as I found that the abundance and richness of the whole avian community was equivalent in restored and reference wetlands. The same was true of richness in wetland-associated birds, although, there was a significantly higher abundance of wetland-associated birds using restored sites than low-disturbance natural ones. A comparison of the community structure and beta diversity may reveal differences not apparent in simple counts of individuals or species.

Differences in avian community composition of my study wetlands were driven by upland-associated birds, as reported in a similar study on avian communities in wetlands in Saskatchewan (Begley et al., 2012). When wetland-associated species were considered in isolation, the avian community composition of restored wetlands fell within the bounds of variability among natural wetlands. Yet, restored sites occupied a more narrow range in bird species space than natural sites when examining the ordination of species composition. In other words, restored wetlands supported lower beta diversity in wetland-associated birds than natural wetlands, as I found when I considered all birds. This contradicts the conclusion that restored wetlands are adequately providing habitat for wetland birds as found by Begley et al. (2012), as some of the natural range of among-wetland variability in wetland-associated bird communities is lost. Based on differences in total avian community composition, and reduced beta diversity of wetland-associated and total birds in restored wetlands compared to natural wetlands, I conclude that restored wetlands have reduced complexity in their avian community composition between sites.

After exploring the avian community composition in restored wetlands and comparing this to the community composition in natural wetlands spanning a gradient in agricultural disturbance, I found that restored wetlands support a statistically distinct assemblage of birds that differs significantly from the avian community composition found in low, medium, and even in high-disturbance natural wetlands when considering all species found (*Table 3-6*). However, a visual interpretation of the data using ordination suggests that the avifauna of restored wetlands overlaps most with the avifauna in highly disturbed wetlands (*Figure 3-5*). This suggests that when replacing natural wetlands with mitigation wetlands, restoration actions are not successful at reinstating avian communities similar to least disturbed sites and may actually lead to reduced avifaunal diversity at the landscape scale. Although there is no difference in the species richness of birds generally or wetland-associated birds at the average restored and natural wetland, there is a significant reduction in beta diversity in restored wetlands. The community differences I observed between restored and low-disturbance, natural wetlands can be explained by two main factors: 1) differences in local and landscape habitat structure, and 2) a reduced variability of wetland hydroperiods in restored sites.

The strong association between the avian community and local and landscape habitat structure is described in my first data chapter and is well established in the literature (e.g., Fairbairn and Dinsmore, 2001; Naugle et al., 2001; Puchniak, 2002; O'Neal et al., 2008; Begley et al., 2012). The difference in community composition that I observed between restored and natural wetlands is also strongly associated with local and landscape habitat structure. One of the major distinctions was that low-disturbance, natural wetlands supported more tree-associated birds, suggesting that restored wetlands are situated in deforested landscapes relative to natural wetlands and that they support less woody wetland vegetation. Begley et al. (2012) also found that natural wetlands supported more bird species characteristic of forested uplands than restored wetlands. In congruence with these results, I found low- and medium-disturbance wetlands supported more species with forest-dependent traits (tree-dwelling species, herein), including Red-breasted Nuthatch (*Sitta canadensis*), White-throated Sparrow (*Zonotrichia albicollis*), and Least Flycatcher (*Empidonax minimus*), based on feeding, nesting, and habitat requirements outlined in Ehrilich et al. (1988). I also observed higher average (± standard deviation) proportions of forest cover within 500 m of low-disturbance (54.4% ± 26.3%) than at restored sites (15.5% ± 13.9 %). Accordingly, in reference, low-disturbance wetlands the abundance of tree-nesting species is strongly correlated with the proportion of woody vegetation within a wetland (Pearson's r = 0.45), then, it is not that all low-disturbance sites support abundant tree-nesting birds, but that the variation in woody vegetation composition of the low-disturbance wetlands leads to higher beta diversity.

Restored wetlands supported an avifauna most similar to the assemblage of birds occupying high-disturbance wetlands, although they were statistically significantly distinct. Likely, this was because the local and landscape habitat characteristics of restored wetlands were most similar to those of high-disturbance wetlands. Bird species tolerant of agricultural disturbance (e.g., Song Sparrow (*Melospiza melodia*) and Savannah Sparrow (*Passerculus sandwichensis*)) were most strongly associated with restored and high-disturbance wetlands. Similarly to highly-disturbed, natural wetlands, restored wetlands were situated in landscapes with more agricultural activity (average ± standard deviation of cultivated: 25.7% ± 22.7%; pasture: 36.1% ± 19.1%). However, not all species common to highly-disturbed, natural sites were present in restored sites. Notable species never observed in restored wetlands, but seen in highly disturbed natural ones include Barn Swallow (*Hirundo rustica*), Brown-headed Cowbird (*Molothrus ater*), Killdeer (*Charadrius vociferus*), and Vesper Sparrows (*Pooecetes gramineus*), which are also associated with agricultural activity (Ehrilich et al., 1988). As with the increased abundance of wetland-associated birds in restored sites, the exclusion of Killdeer and parasitic Brown-headed Cowbirds suggests that restoration is having a positive effect in reducing the abundance of some agriculture-associated birds, even if it does not support the full range of bird diversity evident in low-disturbance natural wetlands.

The second driver explaining differences between restored sites and natural wetlands, including disturbed ones, has to do with difference in hydroperiod. The avian community composition is affected by the divergence in local habitat characteristics of restored and low-disturbance wetlands (Begley et al., 2012; Delphey and Dinsmore, 1993; VanRees-Siewert and Dinsmore, 1996). High-disturbance and restored wetlands supported more species associated with open water and deeper wetlands: e.g., Northern Shoveler (*Anas clypeata*), Blue-winged Teal

(*Anas discors*), and Red-winged Blackbird (*Agelaius phoeniceus*). The local habitat characteristics of restored sites trended towards being deeper with more open water, and more permanent than low-disturbance sites, all effects not unique to restored PPR wetlands (Cole et al., 2006; Hoeltje and Cole, 2007) yet, these differences in depth and amount of open water were not significant among my study sites. A distinct shift in the avian community of restored wetlands was evident, with these sites supporting more waterfowl species and less forest-dwelling passerines than low disturbance, natural wetlands (Begley et al., 2012).

3.5 Conclusions

When evaluating restoration outcomes, it is necessary to re-visit restoration goals and objectives (Jackson et al., 1995). The Alberta wetland policy primary goal is to "…conserve, restore, protect, and manage Alberta's wetlands to sustain the benefits they provide to the environment, society, and the economy," (Government of Alberta, 2013, pg. 8). In the context of Alberta's mitigation policy, the avian community composition of restored wetlands in the Parkland region of Alberta is not reflective of low-disturbance, natural wetlands. Restored wetlands were more similar to high-disturbance, natural wetlands than to low-disturbance, 'reference condition' wetlands. Restoration was therefore not very successful in re-establishing bird communities that resembled least disturbed, reference conditions, and the consequence of this failure is the decline in beta diversity and the loss of tree-associated avian species. Although, when evaluating restoration outcomes against Ducks Unlimited Canada's broad goals to ensure abundant waterfowl for Canadians (Ducks Unlimited Canada, n.d.), restoration can be viewed as more successful in recovering wetland-associated birds.

It is important to understand the functions that are being lost in the landscape when using restoration to compensate for the loss of natural wetlands. Wetland mitigation policy should be structured to ensure the success of restoration projects using refined regional goals and objectives to be met by restoration practitioners. Restoration targets for a region should be representative of the wetlands that are being lost in that region and the historical distribution of wetland sizes and classes in that region (Begley et al., 2012; Fairbairn and Dinsmore, 2001; Naugle et al., 2001). Based on discrepancies in the avian community composition of restored sites compared to natural wetlands, more restoration guidelines are needed for mitigation wetlands to ensure the replacement of lost wetland functions in the Parkland region of Alberta. Currently, restoration projects are successfully creating waterfowl habitat, but are not offsetting the loss of habitat provided by natural wetlands for all avian species.

My results indicate that to-date wetland restoration projects in the Parkland region of Alberta are not encompassing the full extent of natural variability of wetlands at the site and landscape-level, and effort is needed to ensure that restoration projects adequately represent the natural wetlands of the region. The local and landscape characteristics of wetlands affect habitat quality and use by avian species (Begley et al., 2012; Naugle et al., 2001; O'Neal et al., 2008; Shutler et al., 2000). The landscape context of a wetland influences the habitat quality of a restored wetland, and the lack of forest and woody vegetation in a site act as a coarse filter, excluding certain avian species (Naugle et al., 2001; O'Neal et al., 2008). Plantings of willow, birch, and alder shrubs could improve the suitability of restored wetlands for more shrub and tree-dependent birds that appear otherwise excluded from avian communities in restored wetlands. Further, although planting forests is likely beyond the scope of any wetland restoration project, restoration agents could also increase the probability of success by targeting areas for restoration that are in the vicinity of forest patches or in more heavily forested landscapes.

Lastly, my results indicate that restored wetlands are not mimicking the hydrologic variability of natural wetlands adequately. While temporary, seasonal and semi-permanent wetland classes were targeted in the restoration projects I studied, restored wetlands resembled more permanent wetland classes. An improved understanding of hydrologic controls and more accurate models could help restoration agents achieve the desired permanence class. Alternatively, increased management of hydrology at restored wetlands has been found to increase bird use of wetlands as migratory stops in Illinois (O'Neal et al., 2008). More active management of existing restored wetlands could mimic the variations in ponded-water permanence characteristic of temporary and seasonal wetland classes. This could improve the capacity of our existing inventory of restored wetlands to support the avifauna now losing habitat through the process of wetland mitigation banking.

3.6 Figures

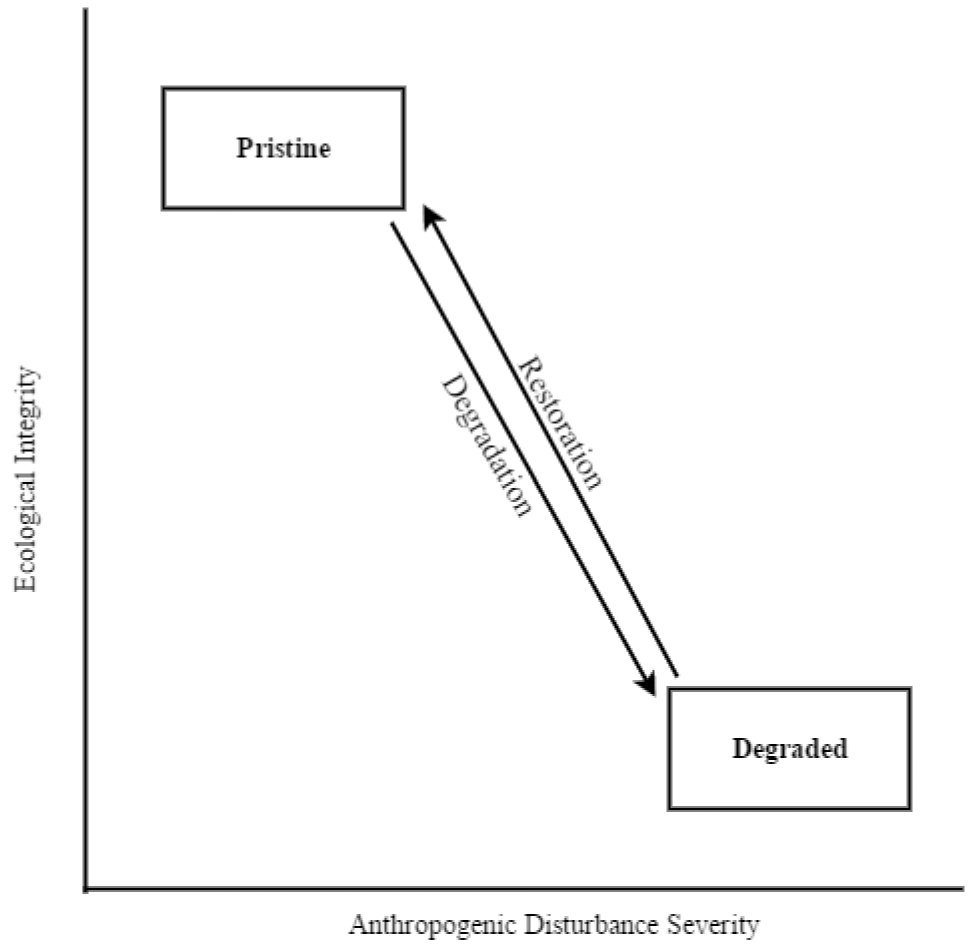

Figure 3-1. Conceptual model depicting a straight path trajectory between pristine and degraded states in response to human disturbance. This trajectory is based on the premise that wetland ecological integrity is altered when the wetland is subjected to anthropogenic activities, such as agriculture, resulting in a progression to a highly degraded state. Restoration activities are hypothesized to reverse this trajectory, returning degraded states to pristine conditions. This conceptual model is based on the gradual, continuous change model of ecosystem dynamics (Suding and Hobbs, 2009).

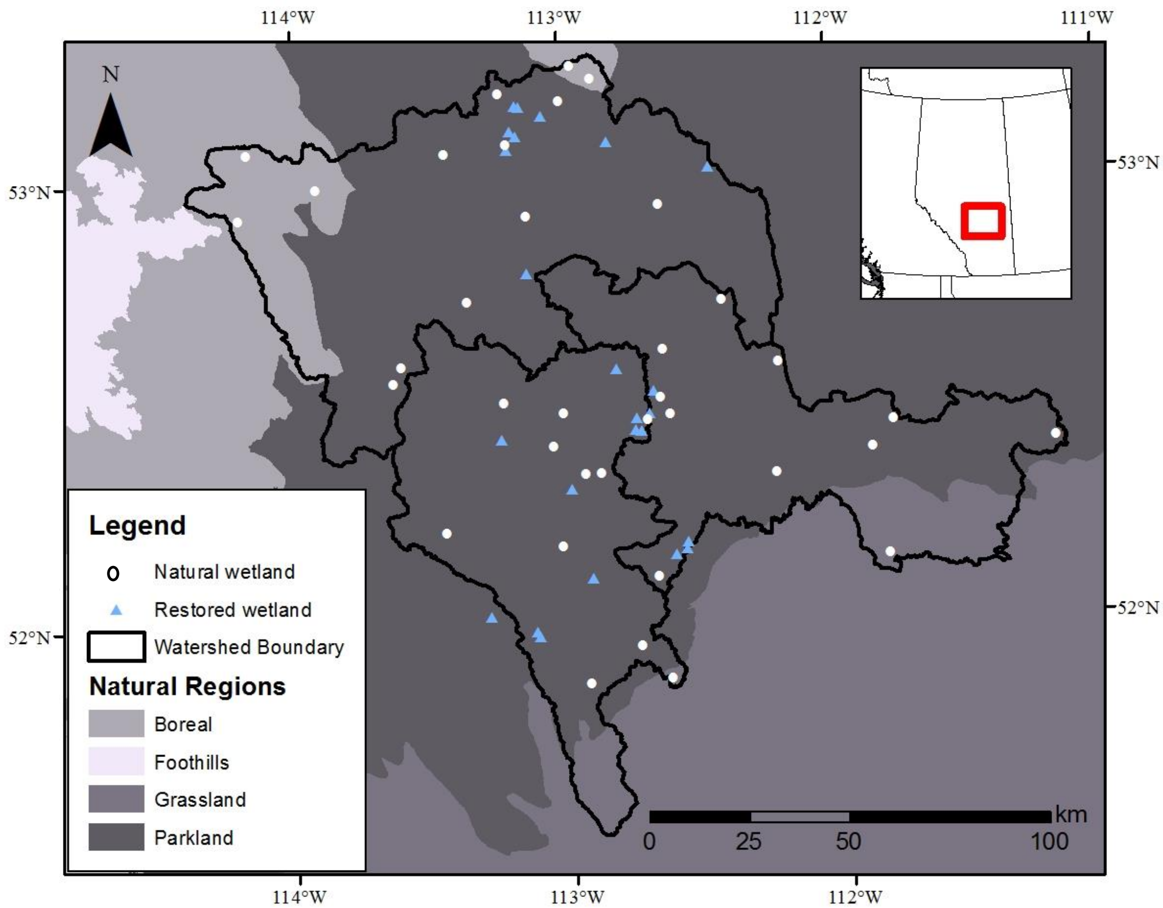

Figure 3-2. Map of sampling locations within the Parkland Natural Region in Alberta, Canada. Symbology reflects wetland type: blue triangles depict restored study wetlands, and white circles depict natural wetlands.

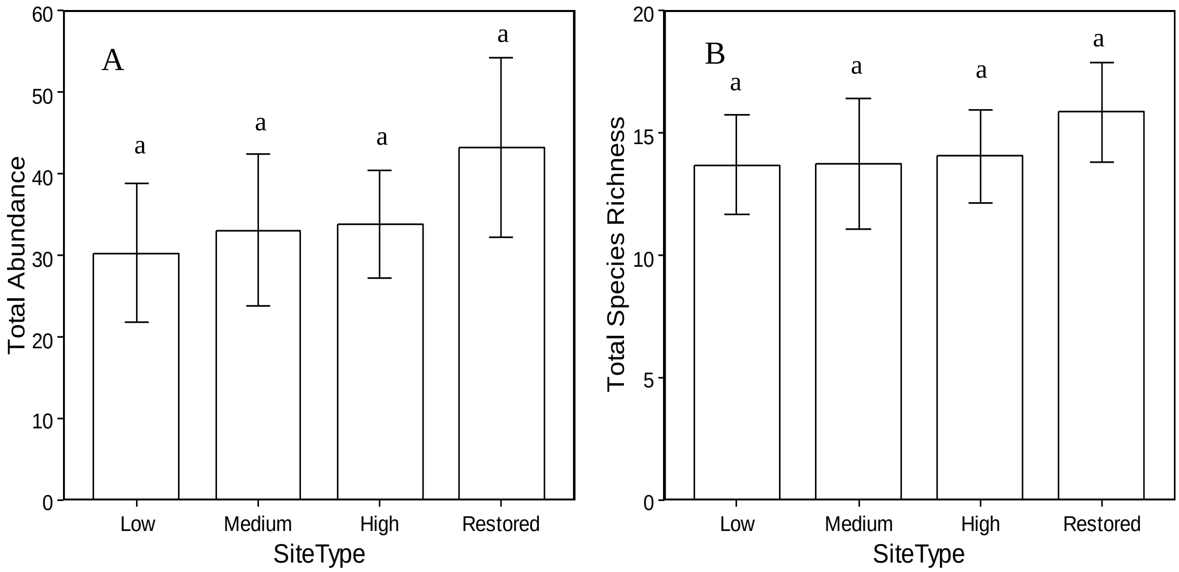

Figure 3-3. Comparison of mean total avian abundance among site types (A: $F_{3,56} = 1.511$, $p = 0.222$) and mean bird richness among site types (B: $F_{3,56} = 1.161$, $p = 0.333$). Error bars represent 95% CI. n = 60 sites.

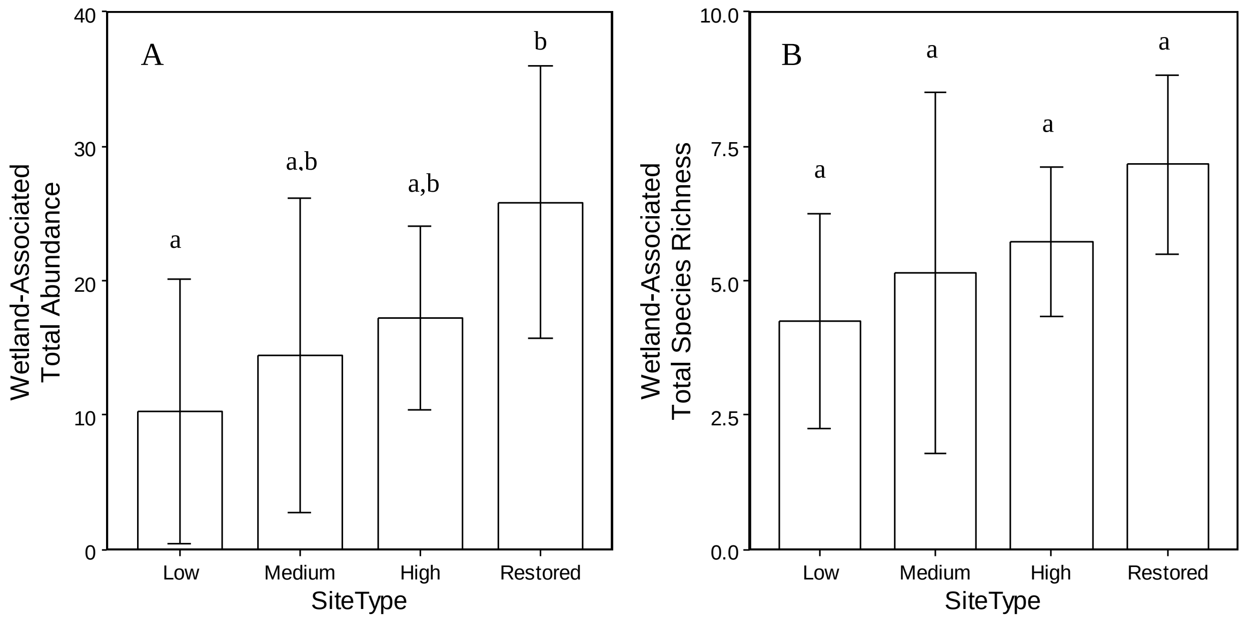

Figure 3-4. Comparison of mean wetland-associated avian total abundance among site types (A: $F_{3,53} = 3.13$, $p = 0.033$), restored sites have higher total abundance of wetland-associated species than low disturbance sites ($p = 0.041$), while no difference in mean wetland-associated total avian richness among site types (B: $F_{3,53} = 2.19$, $p = 0.100$). Error bars represent 95% CI. n = 57 sites.

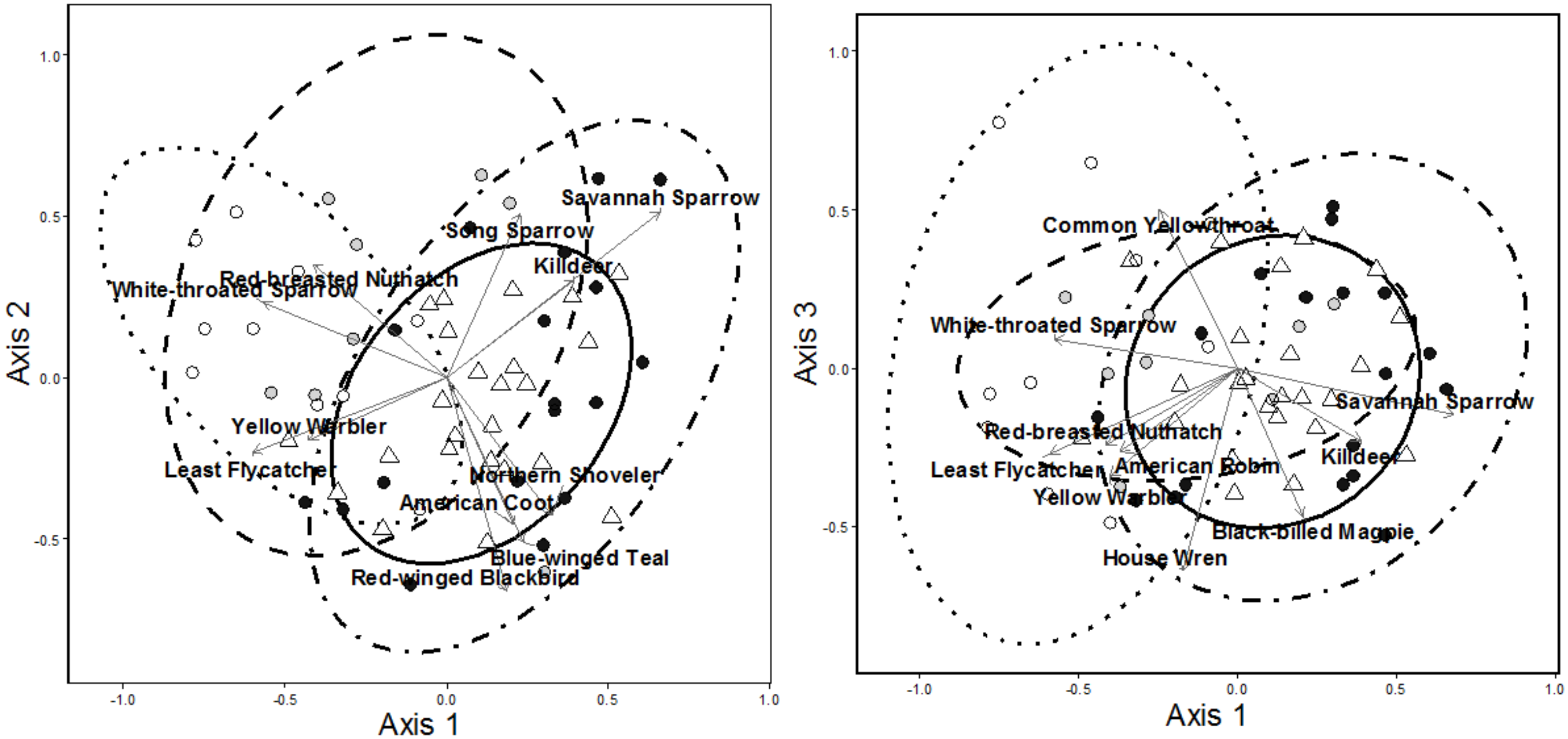

Figure 3-5. Non-metric multidimensional scaling (NMDS) ordination depicting avian community composition in 60 wetlands in the Parkland region of Alberta. Symbology reflects disturbance level: Low (n = 10; white circles); Medium (n = 8; grey circles); High (n = 18; black circles); and Restored (n = 24; triangles). Species abundances that were strongly correlated ($r^2 > 0.2$) with NMDS axes are depicted as vectors and overlaid on ordinations. 90% confidence ellipses are drawn around the clusters of different site types, (Low = dotted line; Medium = dashed and dotted line; High = dashed line; Restored = solid line). Axis 1 shows a continuous, gradual change in community composition along a gradient in agricultural disturbance intensity in natural sites. However, the restored sites overlap more with disturbed wetlands than reference sites, suggesting that restoration is not recovering avian communities similar to low-disturbance, natural wetlands.

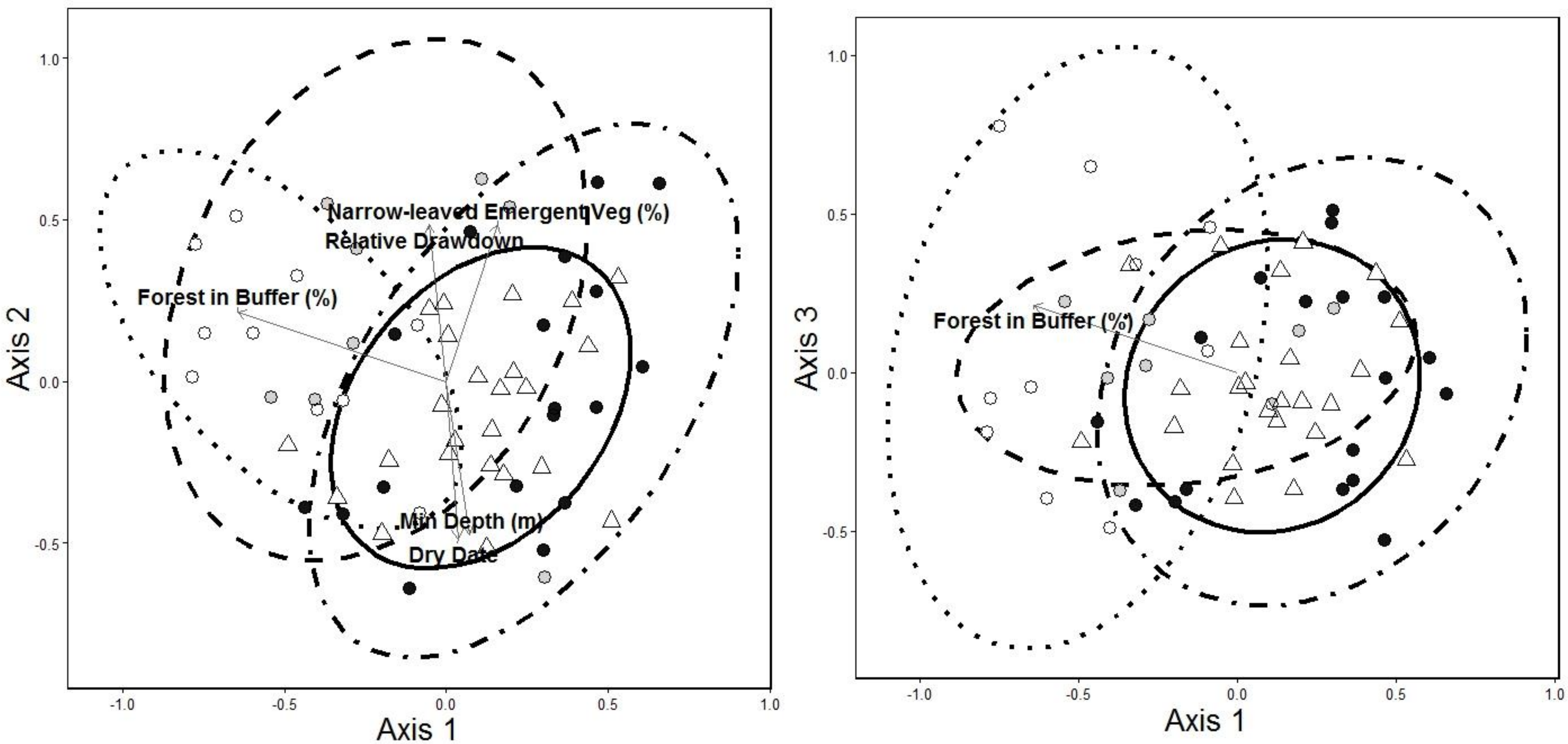

Figure 3-6. Non-metric multidimensional scaling (NMDS) ordination depicting avian community composition in 60 wetlands in the Parkland region of Alberta, as found in *Figure 3-4*. The distinction is that here vectors represent local and landscape level habitat variables. Symbology reflects disturbance level: Low (n = 10; white circles); Medium (n = 8; grey circles); High (n = 18; black circles); and Restored (n = 24; triangles). Local and landscape habitat variables that were strongly correlated ($r^2 > 0.2$) with NMDS axes are depicted as vectors and overlaid on ordinations. 90% confidence ellipses are drawn around disturbance groups, (Low = dotted line; Medium = dashed and dotted line; High = dashed line; Restored = solid line).

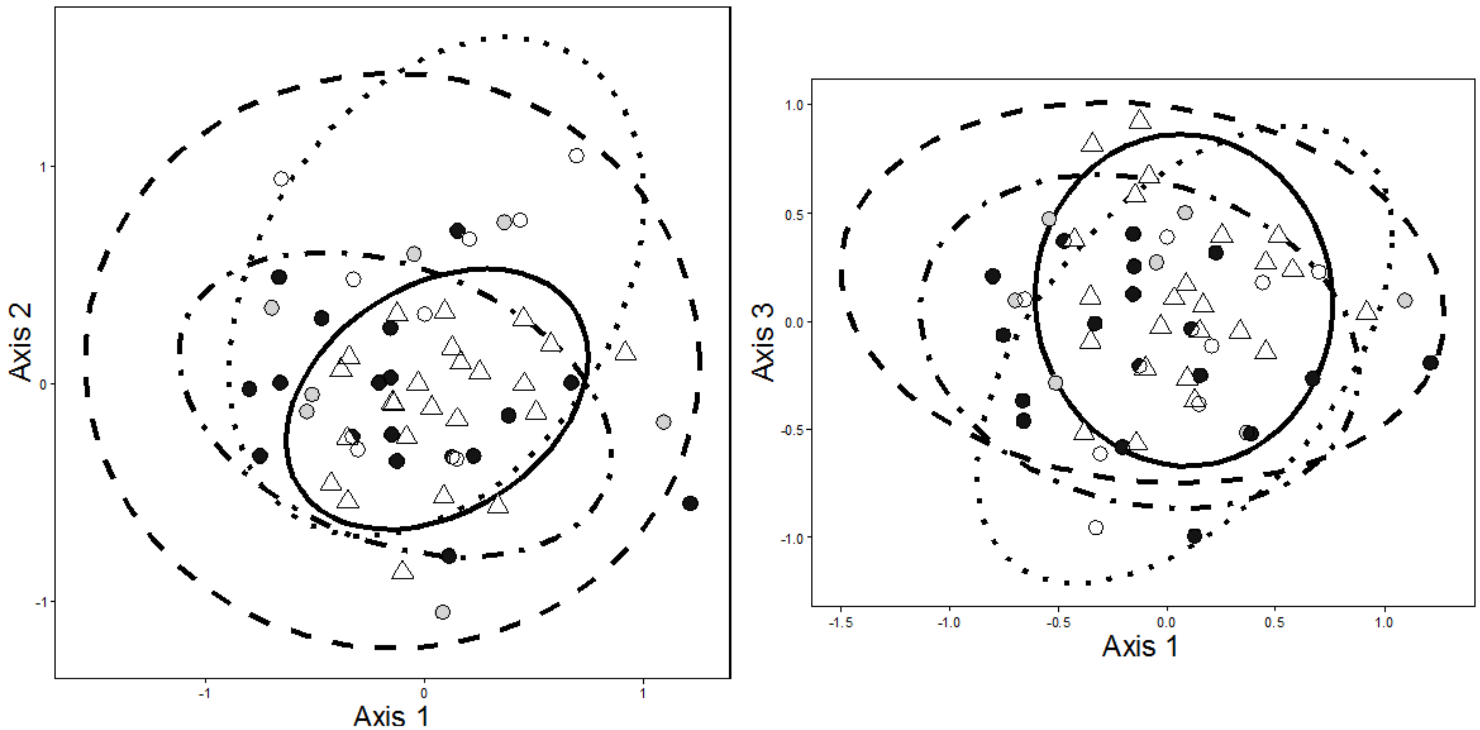

Figure 3-7. Non-metric multidimensional scaling (NMDS) ordination depicting the wetland-associated avian community composition in 57 wetlands in the Parkland region of Alberta. Symbology reflects disturbance level: Low (n = 8; white circles); Medium (n = 7; grey circles); High (n = 18; black circles); and Restored (n = 24; triangles). 90% Confidence ellipses are drawn around disturbance groups, (Low = dotted line; Medium = dashed and dotted line; High = dashed line; Restored = solid line). Restored wetlands occupy a more narrow range in bird species space than natural sites, with a correspondingly lower beta diversity in wetland-associated birds than natural wetlands. Restored sites have a reduced complexity compared to natural wetlands.

3.7 Tables

Table 3-1. Frequency distribution of the 60 wetlands surveyed over 2014 and 2015 by disturbance bin and wetland permanence class for natural and restored wetlands.

	Disturbance Bin			Permanence Class		
	Low	**Medium**	**High**	**Class II**	**Class III**	**Class IV**
Natural (n = 36)	10	8	18	11	12	13
Restored (n = 24)	NA	NA	NA	5	8	11

Table 3-2. Summary of total abundance and richness for the whole avian community at natural and restored wetlands in the Parkland region of Alberta, mean and standard deviation of parameters based on site types (Low-disturbance: n = 10; Medium-disturbance: n = 8; High-disturbance: n = 18; and Restored: n = 24).

	Total Abundance		**Species Richness**	
	Mean	Std (±)	Mean	Std (±)
Low-disturbance, natural	30.3	12.0	12.7	2.9
Medium-disturbance, natural	33.1	11.1	12.8	3.2
High-disturbance, natural	33.8	13.3	13.0	3.9
Restored	43.3	26.2	14.9	4.8

Table 3-3. Summary of local and landscape habitat variables for natural and restored wetlands in the Parkland region of Alberta, mean and standard deviation of parameters based on site-type groups (Low: n = 10; Medium: n = 8; High: n = 18; Restored: n = 24).

Habitat Variable	Unit of Measure	SITE TYPE							
		Low		Medium		High		Restored	
		Mean	Std (+/-)	Mean	Std (+/-)	Mean	Std (+/-)	Mean	Std (+/-)
LOCAL HABITAT (wtihin wetland boundary)									
Wetland area	m^2	5284	5060	3765	3402	5704	7342	4640	4333
Minimum depth	m	0.17	0.28	0.20	0.35	0.19	0.26	0.28	0.30
Maximum depth	m	0.46	0.27	0.50	0.29	0.48	0.24	0.62	0.27
Amplitude	m	0.29	0.15	0.30	0.18	0.29	0.13	0.34	0.19
Amplitude/maximum depth		0.78	0.35	0.77	0.39	0.73	0.34	0.65	0.34
Date of wetland dry out	Julian Date Number	274	97	257	91	270	90	286	97
Delta $_{18}0$		-13.62	3.39	-11.38	3.18	-10.49	4.22	-10.11	2.45
Delta $_{2}$H		-128.93	16.54	-114.96	19.47	-113.75	23.33	-108.36	11.90
Broad-leaved emergents	% - by area	0.00	0.00	0.00	0.00	5.52	20.21	0.00	0.00
Narrow-leaved emergents	% - by area	45.97	30.85	63.73	37.33	57.32	40.77	57.86	31.60
Robust emergents	% - by area	6.89	12.18	6.78	12.35	4.86	9.60	8.51	18.20
Open water	% - by area	7.92	20.08	13.89	25.96	16.26	25.74	17.87	26.74
Woody vegetation	% - by area	25.27	33.80	12.93	19.26	7.58	17.93	8.18	23.35
Drawdown	% - by area	0.80	1.72	0.06	0.18	0.42	1.14	0.70	2.37
Ground cover	% - by area	13.12	21.59	2.64	5.95	8.04	19.65	6.86	14.18

Habitat Variable	Unit of Measure	SITE TYPE							
		Low		Medium		High		Restored	
		Mean	Std (+/-)	Mean	Std (+/-)	Mean	Std (+/-)	Mean	Std (+/-)
LANDSCAPE (within 500 m buffer)									
Forest	% - by area	54.4	26.3	19.6	11.6	5.2	5.5	15.5	13.0
Wetland	% - by area	5.6	4.7	7.0	9.2	4.2	4.6	12.4	11.9
Water	% - by area	0.8	1.0	1.2	2.3	1.7	3.2	5.4	5.9
Urban	% - by area	4.0	5.7	1.3	2.2	2.8	1.5	2.5	2.0
Cultivated	% - by area	2.4	4.8	18.9	23.3	64.7	29.9	25.7	22.7
Pasture	% - by area	6.6	6.3	30.2	18.5	22.0	25.0	36.1	19.1
Grassland	% - by area	9.1	27.8	5.7	10.5	0.4	1.0	3.8	8.9

Table 3-4. ANOVA results comparing local and landscape habitat variables among natural and restored wetlands based on site type (Low: n = 10; Medium: n = 8; High: n = 18; Restored: n = 24). Asterisks indicate statistical significance at an experiment-wise alpha of 0.05.

HABITAT VARIABLE	**ANOVA**		
	$F_{3,56}$	p	
HYDROLOGY			
Minimum depth	0.66	0.578	
Maximum depth	1.20	0.320	
Amplitude	0.23	0.872	
Amplitude/maximum depth	0.36	0.781	
Date of wetland dry out	0.19	0.905	
LOCAL HABITAT (within wetland boundary)			
Wetland area	0.27	0.847	
Broad-leaved emergents	1.36	0.265	
Narrow-leaved emergents	0.45	0.716	
Robust emergents	0.03	0.992	
Open water	0.45	0.718	
Woody vegetation	1.47	0.233	
Drawdown	0.28	0.841	
Ground cover	0.50	0.686	
LANDSCAPE (within 500m buffer)			
Forest	19.20	< 0. 001	*
Wetland	3.70	0.016	*
Water	3.77	0.016	*
Urban	1.95	0.132	
Cultivated	20.30	< 0.001	*
Pasture	8.10	< 0. 001	*
Grassland	0.99	0.406	

Table 3-5. Pairwise comparison for significant ANOVA results for landscape habitat variables among natural and restored wetlands based on site type (Low: n = 10; Medium: n = 8; High: n = 18; Restored: n = 24). Asterisks indicate statistical significance at an experiment-wise alpha of 0.05, using Tukey's honestly significant difference test for the multiple comparisons.

Landscape Habitat Variable	**ANOVA**	$F_{3,56}$	**p**	
Forest	Site Type	19.2	< 0. 001	*
	Posthoc Pairwise Comparisons			
	Low x Medium		0.005	*
	Low X High		< 0.001	*
	Medium x High		0.016	*
	Low x Restored		< 0 .001	*
	Medium x Restored		0.899	
	High x Restored		0.009	*
Wetland	Site Type	3.7	0.016	*
	Posthoc Pairwise Comparisons			
	Low x Medium		0.999	
	Low X High		0.673	
	Medium x High		0.806	
	Low x Restored		0.412	
	Medium x Restored		0.393	
	High x Restored		0.008	*
Crop	Site Type	20.3	< 0.001	*
	Posthoc Pairwise Comparisons			
	Low x Medium		0.146	
	Low X High		< 0.001	*
	Medium x High		< 0.001	*
	Low x Restored		0 .001	*
	Medium x Restored		0.597	
	High x Restored		< 0.001	*
Pasture	Site Type	8.1	< 0. 001	*
	Posthoc Pairwise Comparisons			
	Low x Medium		0.022	*
	Low X High		0.225	
	Medium x High		0.433	
	Low x Restored		< 0 .001	*
	Medium x Restored		0.864	
	High x Restored		0.016	*

Table 3-6. MRPP results comparing the total avian and wetland associated community composition among natural and restored wetlands based on site type (Low: n = 10; Medium: n = 8; High: n = 18; Restored: n = 24). Asterisks indicate statistical significance at an experiment-wise alpha of 0.05, with a Bonferroni correction for pairwise comparisons.

MRPP	**A**	**p**	
Site Type – all avian species	0.05	0.001	*
Pairwise Comparisons			
Low x Medium	0.02	0.070	*
Low x High	0.05	0.001	*
Medium x High	0.01	0.064	
Low x Restored	0.06	0.001	*
Medium x Restored	0.02	0.006	*
High x Restored	0.02	0.001	*
Site Type – wetland-associated species	< 0.01	0.187	

4 Synthesis and general conclusions

4.1 Overview

The Prairie Pothole Region (PPR) has an abundance of non-permanent wetlands that are important habitat for avian species (Batt et al., 1989; Weller, 1999), and these wetlands have been greatly affected by agricultural drainage and alterations (Gleason et al., 2008; McCauley et al., 2015; Voldseth et al., 2007), with smaller wetlands being affected disproportionally (Bartzen et al., 2010). Much work has been done across North America to evaluate wetland condition to inform wetland conservation policy, with a focus on the development of regional indices of biological integrity (IBI), but most of this work has focused on permanent wetlands. The hydrologic variability of non-permanent wetlands is a defining feature of these wetlands and the natural variability of biological assemblages in these systems makes creating regional assessment tools difficult. Avian communities have been successfully used in IBI's to evaluate wetland condition for permanent wetlands (Wilson and Bayley, 2012), and their potential for non-permanent wetlands has not been explored in the northern extent of the prairie pothole region in Alberta.

Wetland restoration efforts in the PPR have been extensive in response to the large losses and degradation of habitat from agricultural activities, with Ducks Unlimited the primary deliverer of wetland habitat restoration projects in Alberta (Alberta North American Waterfowl Management Plan Partnership, 2013). With the goal of creating wetlands similar to natural, least disturbed wetlands, successful restoration of non-permanent wetlands within the PPR has not been consistent in returning sites back to reference conditions (Begley et al., 2012; Dault, 2001; Delphey and Dinsmore, 1993; VanRees-Siewert and Dinsmore, 1996). Wetland conservation policies that incorporate mitigation hierarchies rely on restoration to compensate for the loss of wetland functions that are deemed unavoidable (Zedler and Callaway, 1999).

In response to the need for science to guide policy implementation, my research addresses some important knowledge gaps identified for the Alberta Wetland Policy (2013). The goals of my thesis were to: 1) develop indices of biological integrity (IBI) for the PPR in Alberta, and 2) evaluate restoration outcomes in a mitigation context through comparing wetland avian community composition at restored and natural wetlands.

4.2 Research Findings

In Chapter 1, I set the context for my research, describing the new wetland policy in Alberta and identifying knowledge gaps and the need for additional research to support policy implementation in regards to assessing wetland condition and evaluating compensation wetlands. I characterized the avian community composition at non-permanent wetlands in the northern extent of PPR in Alberta and highlighted the lack of research investigating bioassessment tools to evaluate the condition of these marshes. For the northern extent of the PPR, I identified the potential to use avifauna as a biological indicator taxon. Lastly, I overviewed the use of restoration for the mitigating of wetland losses, and challenged the need to understand restoration within Alberta and examine whether wetland restoration has the capacity to mitigate wetland losses.

In Chapter 2, I developed and validated IBIs based on metrics derived from the avian assemblage for non-permanent wetlands in the PPR in Alberta. The PPR in Alberta is comprised of two different natural regions, the Parkland and Grassland, which are managed jointly as the ‘white zone’. I found that due to regional differences in the reference condition for each natural region, separate IBIs are needed to increase the discriminatory power of the created IBIs. While I successfully created IBIs for each region, I was not able to validate the IBI for the Grassland region most likely due to inaccuracies in the remotely sensed data.

In Chapter 3, I compared restored wetlands to natural wetlands using avian community composition as the basis of my comparison. I explored restoration outcomes at non-permanent mitigation wetlands. I found that there was a gradual gradient of change in the biological components of wetlands following a continuous gradient in degradation from low- to high-disturbance wetlands, based on differences in the avian community composition and using a space for time substitution. Bird community composition in restored wetlands was more similar to that of highly degraded wetlands, indicating that restoration actions do not return wetlands to low-disturbance conditions. Furthermore, restored wetlands supported lower beta diversity than natural wetlands of any disturbance level. Consequently, I conclude that in a mitigation context, restoration leads to the deterioration of the avifaunal community at the landscape level, with ditch-plugging creating restored wetlands that are all highly similar replicates of one another.

4.3 Implications and Significance

As outlined in the Alberta Wetland Policy (2013), tools are needed to incorporate biological information to inform the decision making process that has determined to evaluate wetlands based on their functional values. My research focused on temporary to semi-permanent wetland permanence classes because: 1) these wetlands are the most frequent in the Grassland and Parkland regions, 2) they are ecologically important due to the wildlife habitat they provide, and 3) the biological components of these wetlands are relatively poorly studied. From Chapter 2, the IBI I created for the Parkland region has the ability to discriminate wetland condition based on the avian assemblage and inform government on wildlife habitat functions provided by wetlands in this region. While my IBI created for the Grassland region was not successfully validated, this failure highlights the importance of having regionally specific assessment tools due to key differences in reference conditions for each of these natural regions within the PPR. While Parkland and Grassland are managed jointly in Alberta, my research suggests that regionally calibrated assessment tools are needed, otherwise the sensitivity of the tool is diminished. Additionally, the Grassland IBI failed to validate in part due to inaccuracies in remotely sensed land cover data from this region. The need for field-verified wetland assessments is underscored by these remotely sensed data quality issues.

To improve our understanding of the current state of temporary to semi-permanent wetland restoration efforts in the Parkland region of Alberta, I used bird communities to compare restored wetlands to natural wetlands. I found evidence that wetland bird communities change in response to anthropogenic degradation, based on a space for time substitution. High- and low-disturbance wetlands supported distinct avian communities, with medium-disturbance wetlands lying in between. Visually, ordinations supported the conclusion of a gradual change in community composition along a gradient in disturbance, with overlap among wetlands of neighboring disturbance classes but a general trend in community composition from low- to high-agricultural disturbance. Restored non-permanent wetlands in my study, however, more closely resembled highly disturbed wetlands in terms of their avifaunal community composition. Restored wetlands constituted a less variable sub-set of the range in bird community composition observed in highly disturbed wetlands. Therefore, my study suggests that wetland policy relying on restoration and enhancement to offset the loss of natural wetlands will fail to maintain the biodiversity and recreational values of non-permanent marshes through declines in the biological integrity of compensatory wetlands compared with natural ones.

To further understand the condition of restored non-permanent wetlands, I applied my Parkland IBI to these wetlands (*Figure 4-1*). While the majority of restored sites had IBI scores that were categorized in 'fair' condition, I anticipated that these sites would have had higher IBI scores based on their relatively low disturbances scores. The avian metrics from the Parkland IBI that scored poorly at restored wetlands were: 1) relative abundance of foliage gleaning species; 2) species richness of shrub-nesting species; and 3) species richness of bark-gleaning species. All three are traits related to the diversity of passerine species that require shrub and tree habitat, as further corroborated by my community analysis in Chapter 3.

These lower than expected IBI scores for restored sites support my findings in Chapter 3 that avian community of restored wetlands is not equivalent to low-disturbance, natural wetlands. Based on the relatively low disturbance scores of restored wetlands (mean ± standard deviation = 82.7 ± 54.1), restoration actions at least partially return environmental conditions to levels found in low-disturbance natural wetlands, yet the avian community in restored wetlands is not representative of the reference avian community. In fact, the slope of the line of best fit among the restored sites plotted in *Figure 4-1* is not significantly different from zero, different from the significant linear slope between biological integrity scores and disturbance scores evident among natural wetlands.

In regards to the Alberta Wetland Policy (2013), my results have implications when adopting a mitigation hierarchy that allows for wetland restoration to compensate for wetland losses. Even after 10 years restored wetlands in the Parkland region of Alberta are not approaching low-disturbance conditions. My results provide evidence that restoration does not reverse degradation outright and precaution must be taken through adapting management actions.

Further guidance is needed to improve restoration success in this region and ensure ecological integrity and functions are not lost on the landscape due to wetland mitigation.

4.4 Future Research

I found that avian communities at non-permanent wetlands were highly influenced by the land cover of the surrounding landscape, which underscores the importance of characterizing disturbance at a wetland. Inaccuracies in the remotely sensed land cover database weakened my ability to validate an IBI for the Grassland region. Further research into characterizing the environmental conditions and degradation at a wetland would allow for further exploration of biological assessment tools for the region. Increased sample sizes would also improve the statistical power when creating alternate wetland assessment tools. While my study focused on the Grassland and Parkland natural regions, the Alberta Wetland Policy (2013) is applicable to all natural regions within the province and regionally calibrated assessment tools are needed across the province.

An increase in restoration projects is anticipated with the implementation of the Alberta Wetland Policy (2013) and further research is needed to guide restoration practices for mitigation wetlands. Comparisons of other biological assemblages (e.g., plants) in restored and natural wetlands may help further guide wetland mitigation in the province. The inability to recover the variable hydrology of non-permanent wetland classes was one characteristic found to greatly impact the biological components of these restored wetlands in my study and further research is needed to improve the hydrology of restored wetlands and accordingly improve wetland restoration success.

4.5 Figures

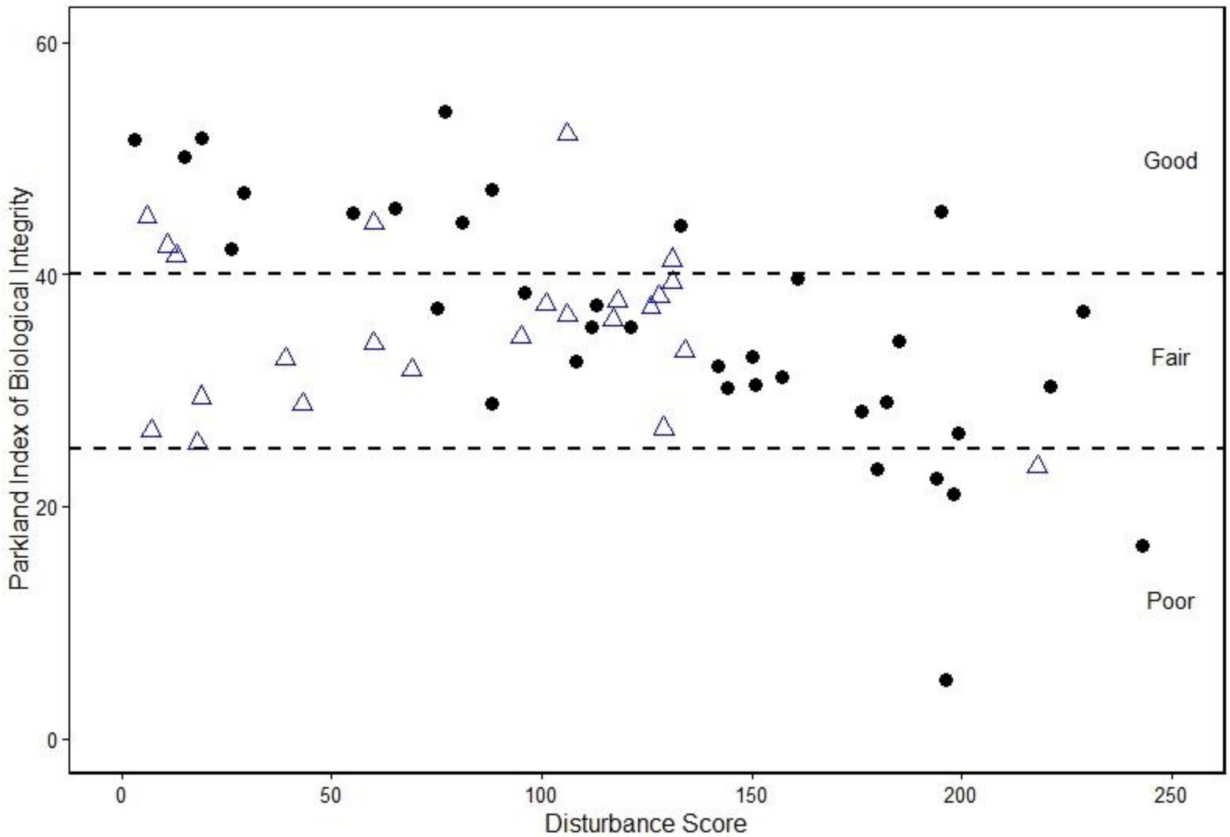

Figure 4-1. Parkland IBI scores for restored sites (open triangles; n = 24) and all natural sites (black, closed circles; n = 36) plotted against the disturbance scores. Wetland condition bins are depicted

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Appendices

Appendix 1. List of all study wetlands for IBI creation in Chapter 2 (n = 72), including coordinates, year sampled, size, permanence class, initial disturbance class used in site collection.

Site ID	Region	Latitude	Longitude	Year	Size (m^2)	Permanence Class	Initial Disturbance Class
98	Grassland	51.90165	111.69733	2014	28221	3	Low
101	Grassland	51.0377	111.31802	2014	15023	3	Low
109	Grassland	51.01003	111.8337	2014	527	4	High
110	Grassland	51.53763	111.50582	2015	15614	3	Low
115	Grassland	51.50547	111.22282	2014	11346	3	High
117	Grassland	51.19809	111.53912	2014	4576	3	High
124	Grassland	51.31596	112.23538	2014	4957	3	Low
131	Grassland	51.28267	112.29461	2014	3563	2	Low
133	Grassland	51.37129	112.18208	2014	1465	3	Low
135	Grassland	51.49276	112.38198	2014	351	4	Low
142	Grassland	51.4136	112.13138	2015	2066	3	Low
145	Grassland	51.60363	112.2061	2014	7038	4	High
149	Grassland	51.47503	112.0392	2014	2930	4	High
152	Grassland	50.36122	111.42416	2014	32375	2	Low
153	Grassland	50.51392	111.50092	2014	13006	4	Low
158	Grassland	50.55512	112.49538	2014	10548	3	Low
165	Grassland	50.31696	111.6562	2014	1725	3	Low
173	Grassland	50.16459	111.53887	2015	29300	3	Medium
184	Grassland	51.41749	112.56838	2015	18783	4	High
186	Grassland	51.83351	111.72227	2014	12216	4	Low
188	Grassland	51.52895	111.32801	2014	10942	3	Medium
202	Grassland	50.36549	112.02317	2015	297	2	Low
203	Grassland	50.65714	112.44987	2014	3819	2	High
308	Grassland	51.57879	112.04148	2015	3096	3	High
312	Grassland	51.4394	112.00307	2015	1151	2	High
336	Grassland	50.94387	111.36891	2015	6462	2	Low
338	Grassland	51.27651	111.66965	2015	5138	2	Medium
345	Grassland	51.16148	111.97274	2015	3797	2	Medium

Site ID	Region	Latitude	Longitude	Year	Size (m^2)	Permanence Class	Initial Disturbance Class
346	Grassland	51.24029	112.08501	2015	7212	3	Medium
360	Grassland	51.74384	111.73608	2015	37604	3	Medium
366	Grassland	51.28624	112.06562	2015	2232	2	Medium
375	Grassland	50.99474	111.63432	2015	2909	2	Low
379	Grassland	51.67981	111.96002	2015	3668	2	Low
384	Grassland	51.23564	111.69373	2015	7646	3	High
388	Grassland	50.95792	111.46562	2015	18441	3	Low
KIN	Grassland	50.44742	111.89	2014	9566	2	Low
10	Parkland	52.51477	112.64787	2014	5499	4	High
13	Parkland	52.33939	112.22819	2015	1759	3	Medium
18	Parkland	52.58656	112.20809	2014	32810	3	High
25	Parkland	52.14848	111.82265	2014	5256	3	High
30	Parkland	52.38929	111.87381	2014	3233	2	High
31	Parkland	52.73904	113.35228	2015	3865	3	Medium
32	Parkland	52.59304	113.59866	2015	3633	2	Low
35	Parkland	53.07183	113.4282	2014	1998	2	Medium
56	Parkland	52.94941	112.63455	2015	1963	4	High
67	Parkland	52.46586	112.69706	2014	1151	2	Low
89	Parkland	52.34631	112.92848	2014	4043	4	High
90	Parkland	52.34705	112.87226	2014	2473	4	High
182	Parkland	52.73056	112.4106	2014	3443	2	High
187	Parkland	52.62288	112.63221	2014	6942	4	High
190	Parkland	53.09104	113.197	2014	4995	4	High
194	Parkland	52.21956	113.44279	2014	6653	4	Medium
195	Parkland	52.41014	113.04399	2015	12973	4	High
200	Parkland	52.47809	112.61372	2014	10704	4	Medium
301	Parkland	51.87547	112.92802	2015	1101	2	High
317	Parkland	53.18687	112.9959	2015	4445	2	High
321	Parkland	52.44961	111.79378	2015	1531	2	High
333	Parkland	53.26561	112.9496	2015	11037	4	Low
344	Parkland	52.11278	112.67157	2015	6290	3	High
351	Parkland	53.20609	113.21928	2015	3125	2	High
365	Parkland	52.92827	113.1265	2015	1041	3	Medium
368	Parkland	52.39511	111.19943	2015	625	3	Medium
377	Parkland	52.4848	113.00462	2015	358	2	High

Site ID	Region	Latitude	Longitude	Year	Size (m^2)	Permanence Class	Initial Disturbance Class
395	Parkland	51.95862	112.74086	2015	2186	3	High
396	Parkland	53.07396	114.16621	2015	567	3	Low
398	Parkland	52.99462	113.90918	2015	3476	4	Medium
BATL	Parkland	52.92772	114.19742	2014	4114	4	Low
GAD	Parkland	52.50925	113.22429	2014	3614	3	Low
JJCOLL	Parkland	52.55746	113.63092	2014	16175	3	Low
MIQ	Parkland	53.23397	112.87446	2014	8559	4	Low
RUM	Parkland	51.88395	112.63176	2015	2303	3	Low
TOL	Parkland	52.18618	113.0198	2014	1690	2	Low

Appendix 2 . Disturbance Index Calculation

IBI development requires an objective basis for ranking wetlands. For my study region, there were no existing quantitative or qualitative tools to rank wetlands from the least to most disturbed condition. I created a qualitative disturbance index that used the extent of non-natural land cover around each wetland as the basis for determining wetland condition. I determined that the extent of non-natural disturbance within a 500 m buffer did not adequately characterize the non-natural disturbance at a site, as within wetland disturbances also influenced wetland condition. To represent within wetland non-natural disturbances, I included modifiers in my index to build upon the disturbances characterized in the 500m buffer around each wetland. The within wetland disturbance modifiers that I included were the presence of cattle disturbance, soil pesticides, and within wetland agricultural activity. The modifiers I included in my disturbance index were common categories used in existing qualitative, rapid assessment tools (Fennessy et al., 2007; Mack, 2007).

The disturbance index scored sites initially based on the % non-natural land cover within a 500 m buffer, for example, if a site had 38 % non-natural cover within the buffer, the wetland was assigned 38 points. Next, based on my additional modifiers, the wetland may score higher due to more within wetland disturbances. If cattle disturbance was detected within the delineated wetland boundary, it was determined to be either low or high intensity and assigned more points accordingly, 25 points for low intensity, 50 points for high intensity, and 0 points if absent. A composite sediment sample was collected at all wetlands in August and was analyzed for a comprehensive list of pesticides (*Table A*). For my index, I assigned an addition 50 points if the presence of any pesticides were detected in the sediment at a wetland. For the purpose of characterizing any existing within wetland disturbances, I excluded legacy compounds: any nonregistered or delisted pesticides. For the last modifier, if any agricultural activity was evident within the delineated wetland boundary, an addition 50 points were added to the disturbance score. The total possible disturbance index score was 250 points, with higher scores representing sites with higher levels of non-natural disturbance.

Example calculation:

Site 117

Disturbance Index Scoring Criteria	**Site Information**	**Score**
Percent non-natural land cover in 500 m buffer around wetland	91 %	91
Cattle disturbance	None	0
Sediment pesticides	Present	50
Buffer: Agricultural activity within wetland	Absent	0
		141

Disturbance index score: 141

Table A. Pesticide compounds that were analyzed for in wetland sediment samples. Only registered pesticides included.

Pesticide compounds	
2,4-Dichlorophenoxyacetic acid	Fenoxaprop
2,4-Dichlorophenol	Fluroxypyr
Azoxystrobin	Imazamethabenz
Bentazon	Iprodione
Bromoxynil	MCPA (2-methyl-4-chlorophenoxyacetic acid)
Boscalid	Propiconazole
Chlorothalonil	Propoxur
Chlorpyrifos	Prothioconazole-Desthio
Clopyralid	Quizalofop-ethyl
Diazinon	Tebuconazole
Diclofop	Triallate
Difenoconazole	Trifluralin
Ethalfluralin	Triticonazole

Appendix 3. Site characteristics used to calculate disturbance scores (as described in Appendix 2), final disturbances scores used in IBI development and validations for all IBIs, and distinction of sites used for validation of IBIs.

Site ID	Non-natural Cover (%)	Cow Intensity (0 - None, 1- Low, 2 - High)	Sediment Pesticides (without legacies)	Buffer (Agriculture in wetland, 0 - buffer, 1 - buffer)	Disturbance Score	Validation Dataset
98	0	1	0	1	75	
101	0	2	1	1	150	X
109	86	2	1	1	236	
110	22	2	1	1	172	X
115	97	1	1	1	222	
117	91	0	1	0	141	
124	0	1	1	1	125	
131	0	2	1	1	150	X
133	14	1	0	1	89	
135	29	1	1	1	154	
142	0	1	1	1	125	X
145	95	1	0	1	170	
149	86	0	1	1	186	
152	5	1	1	1	130	X
153	5	0	1	0	55	
158	0	1	0	1	75	
165	0	2	0	1	100	X
173	69	1	0	1	144	
184	100	0	1	1	200	
186	0	2	1	1	150	
188	73	0	1	1	173	X

Site ID	Non-natural Cover (%)	Cow Intensity (0 - None, 1- Low, 2 - High)	Sediment Pesticides (without legacies)	Buffer (Agriculture in wetland, 0 - buffer, 1 - buffer)	Disturbance Score	Validation Dataset
202	23	1	0	1	98	
203	100	2	0	1	200	X
308	69	1	0	1	144	X
312	95	0	0	1	145	
336	0	1	0	1	75	X
338	27	1	0	1	102	
345	78	1	0	1	153	
346	41	1	1	1	166	
360	66	2	1	1	216	
366	43	0	0	1	93	
375	3	2	1	1	153	
379	4	2	1	1	154	
384	88	1	0	1	163	
388	3	1	1	1	128	
KIN	10	1	1	1	135	
10	79	2	1	1	229	X
13	44	2	0	1	144	
18	82	0	1	1	182	
25	80	0	1	1	180	
30	96	0	1	1	196	
31	62	0	0	1	112	X
32	13	1	0	1	88	
35	45	2	1	1	195	
56	98	0	1	1	198	X
67	27	0	1	0	77	
89	94	0	1	1	194	X

Site ID	Non-natural Cover (%)	Cow Intensity (0 - None, 1- Low, 2 - High)	Sediment Pesticides (without legacies)	Buffer (Agriculture in wetland, 0 - buffer, 1 - buffer)	Disturbance Score	Validation Dataset
90	100	0	0	1	150	
182	99	0	1	1	199	X
187	76	0	1	1	176	
190	92	0	1	0	142	
194	36	1	1	1	161	
195	8	2	0	1	108	X
200	46	0	1	0	96	
301	85	0	1	1	185	
317	57	2	0	1	157	
321	93	2	1	1	243	
333	13	1	0	1	88	
344	81	0	0	0	81	X
351	71	2	1	1	221	X
365	26	0	0	0	26	
368	13	2	0	1	113	X
377	71	0	1	0	121	X
395	51	2	0	1	151	X
396	29	0	0	0	29	
398	65	0	0	0	65	X
BATL	5	0	1	0	55	
GAD	19	0	0	0	19	
JJCOLL	15	0	0	0	15	
MIQ	3	0	0	0	3	
RUM	0	1	0	1	75	
TOL	8	1	1	1	133	

Appendix 4. Avian traits used to compile metrics for IBI, based on previous studies (Croonquist and Brooks, 1991; De Graaf et al., 1985; O’Connell et al., 1998; Veselka et al., 2010) and natural history information (DeGraaf et al., 1991; Ehrilich et al., 1988).

	Habitat Preference		Diet Classification		Primary Feeding Habit											
Bird Code[1]	Obligate Wetland	Specialist	Carnivore	Omnivore	Herbivore	Insectivore	Ground Gleaner	Foliage Gleaner	Aerial Forager	Hawk & Pursuit	Hover & Glean	Bark Gleaner	Hawks	Surface Diver	Dabbler	Stalking	Probes
ALFL			1			1							1				
AMAV	1	1	1			1											1
AMBI	1	1	1													1	
AMCO	1				1										1		
AMCR				1			1										
AMGO					1			1									
AMRE			1			1		1									
AMRO				1			1										
AMWI	1			1											1		
BAIS		1		1			1										
BAOR				1		1		1									
BARS			1			1			1								
BBMA				1			1										
BCCH				1		1		1									
BHCO				1			1										
BLJA				1			1										
BLTE	1		1			1							1				
BNST	1	1	1			1											1
BOGU						1									1		
BRBL				1			1										
BRTH				1			1										
BUFF	1	1				1								1			
BWTE	1			1											1		
CANG	1				1		1								1		

Bird Code[1]	Obligate Wetland	Specialist	Carnivore	Omnivore	Herbivore	Insectivore	Ground Gleaner	Foliage Gleaner	Aerial Forager	Hawk & Pursuit	Hover & Glean	Bark Gleaner	Hawks	Surface Diver	Dabbler	Stalking	Probes
CANV	1			1										1			
CCSP				1			1										
CEDW				1				1									
CHSP				1			1										
CITE	1			1											1		
COGR				1			1										
COLO	1	1	1											1			
CORA				1			1										
COYE			1			1		1									
DOWO				1		1						1					
EAGR	1		1			1								1			
EAKI				1									1				
EAPH				1		1							1				
EUST				1			1										
FISP				1			1										
FRGU	1			1			1										
GADW	1			1											1		
GBHE	1		1													1	
GRCA				1			1										
GRSP				1		1	1										
GWTE	1			1											1		
HAWO			1									1					
HOGR	1		1											1			
HOLA		1		1			1										
HOSP				1			1										
HOWR			1			1	1										
KILL			1			1	1										
LBCU			1														1
LCSP				1			1										
LEFL			1			1					1						
LESA	1	1	1			1	1										
LESC	1			1										1			
LEYE	1		1			1											1

Bird Code[1]	Obligate Wetland	Specialist	Carnivore	Omnivore	Herbivore	Insectivore	Ground Gleaner	Foliage Gleaner	Aerial Forager	Hawk & Pursuit	Hover & Glean	Bark Gleaner	Hawks	Surface Diver	Dabbler	Stalking	Probes
LISP				1		1	1										
MAGO			1			1											1
MALL	1			1											1		
MERL			1							1							
MODO					1		1										
NESP	1			1			1										
NOFL				1		1	1										
NOHA			1							1							
NOPI	1			1											1		
NRWS			1			1			1								
NSHO	1			1											1		
OVEN		1	1			1	1										
PIWO						1						1					
RBGR				1				1									
RBGU	1			1			1										
RBNU			1			1						1					
RCKI			1			1		1									
REDH	1			1										1			
REVI				1		1					1						
RNDU	1			1										1			
RNEP				1			1										
RTHA			1							1							
RUBL				1		1	1										
RUDU	1					1								1			
RUGR				1				1									
RWBL				1			1										
SACR	1			1													1
SAVS				1		1	1										
SORA	1			1			1										
SOSP				1			1										
SPPI		1		1		1	1										
SWHA			1							1							
SWSP	1			1			1										
SWTH				1				1									

Bird Code[1]	Obligate Wetland	Specialist	Carnivore	Omnivore	Herbivore	Insectivore	Ground Gleaner	Foliage Gleaner	Aerial Forager	Hawk & Pursuit	Hover & Glean	Bark Gleaner	Hawks	Surface Diver	Dabbler	Stalking	Probes
TEWA				1				1									
TRES			1			1			1								
UPSA			1			1	1										
VESP				1			1										
WAVI				1		1		1									
WEME				1			1										
WILL	1		1														1
WIPH	1		1			1									1		
WISN	1		1			1											1
WTSP				1			1										
YEWA			1			1		1									
YHBL	1			1		1	1										

[1]Bird codes according to the American Ornithologists Union standards (American Ornithologists' Union, 1983)

	Grouped Feeding Habits		Primary Diet													Conservation Status	
Bird Code[1]	Water Feeder	Shoreline Feeder	Insects	Aquatic Insects	Carrion	Seeds	Fruit	Grains	Aquatic Plants	Small Animals	Amphibians	Birds	Plants	Nuts	Fish	Special Concern	Exotic
ALFL	0	0	1														
AMAV	0	1		1													
AMBI	0	1	1	1						1	1	1			1		
AMCO	1	0							1								
AMCR	0	0	1			1					1	1	1	1			
AMGO	0	0				1											
AMRE	0	0	1														
AMRO	0	0	1				1										
AMWI	1	0		1					1								
BAIS	0	0	1			1											
BAOR	0	0	1														
BARS	0	0	1														
BBMA	0	0	1		1						1						
BCCH	0	0	1														
BHCO	0	0	1			1											
BLJA	0	0	1			1	1				1			1			
BLTE	0	0	1														
BNST	0	1		1													
BOGU	1	0		1											1		
BRBL	0	0	1			1							1				
BRTH	0	0	1				1	1			1			1			
BUFF	1	0		1													
BWTE	1	0		1		1			1								
CANG	1	0				1			1								
CANV	1	0		1					1								
CCSP	0	0	1			1											
CEDW	0	0	1				1										
CHSP	0	0	1			1											
CITE	1	0		1		1			1								
COGR	0	0	1	1		1	1	1			1			1	1		
COLO	1	0		1											1		

Bird Code[1]	Water Feeder	Shoreline Feeder	Insects	Aquatic Insects	Carrion	Seeds	Fruit	Grains	Aquatic Plants	Small Animals	Amphibians	Birds	Plants	Nuts	Fish	Special Concern	Exotic
CORA	0	0	1		1	1	1	1		1	1	1			1		
COYE	0	0	1														
DOWO	0	0	1				1										
EAGR	1	0		1													
EAKI	0	0	1				1										
EAPH	0	0	1														
EUST	0	0	1			1	1	1									1
FISP	0	0	1			1											
FRGU	0	0	1			1		1		1					1		
GADW	1	0		1				1	1					1			
GBHE	0	1		1						1	1				1		
GRCA	0	0	1				1										
GRSP	0	0	1														
GWTE	1	0				1		1	1								
HAWO	0	0	1			1	1										
HOGR	1	0		1											1		
HOLA	0	0	1			1											
HOSP	0	0	1			1	1	1									1
HOWR	0	0	1														
KILL	0	0	1														
LBCU	0	1	1	1												1	
LCSP	0	0	1			1											
LEFL	0	0	1														
LESA	0	0	1	1													
LESC	1	0		1		1			1								
LEYE	0	1	1	1													
LISP	0	0	1														
MAGO	0	1	1	1													
MALL	1	0		1		1		1	1								
MERL	0	0										1					
MODO	0	0				1		1									
NESP	0	0	1			1											
NOFL	0	0	1														

Bird Code[1]	Water Feeder	Shoreline Feeder	Insects	Aquatic Insects	Carrion	Seeds	Fruit	Grains	Aquatic Plants	Small Animals	Amphibians	Birds	Plants	Nuts	Fish	Special Concern	Exotic
NOHA	0	0								1	1	1					
NOPI	1	0		1		1			1								
NRWS	0	0	1														
NSHO	1	0		1		1			1								
OVEN	0	0	1														
PIWO	0	0	1														
RBGR	0	0	1			1	1										
RBGU	0	0	1				1	1		1					1		
RBNU	0	0	1														
RCKI	0	0	1														
REDH	1	0		1					1								
REVI	0	0	1														
RNDU	1	0		1					1								
RNEP	0	0	1			1	1	1			1						1
RTHA	0	0								1	1						
RUBL	0	0	1													1	
RUDU	1	0		1													
RUGR	0	0	1			1	1				1		1				
RWBL	0	0	1														
SACR	0	1	1	1		1	1	1	1	1		1					
SAVS	0	0	1														
SORA	0	0	1	1		1											
SOSP	0	0	1			1											
SPPI	0	0	1													1	
SWHA	0	0	1							1	1						
SWSP	0	0	1			1											
SWTH	0	0	1				1										
TEWA	0	0	1				1										
TRES	0	0	1														
UPSA	0	0	1														
VESP	0	0	1			1											
WAVI	0	0	1														
WEME	0	0	1			1		1									
WILL	0	1		1													

Bird Code[1]	Water Feeder	Shoreline Feeder	Insects	Aquatic Insects	Carrion	Seeds	Fruit	Grains	Aquatic Plants	Small Animals	Amphibians	Birds	Plants	Nuts	Fish	Special Concern	Exotic
WIPH	1	0		1													
WISN	0	1	1	1													
WTSP	0	0	1			1	1										
YEWA	0	0	1														
YHBL	0	0	1														

[1]Bird codes according to the American Ornithologists Union standards (American Ornithologists' Union, 1983)

	Migration habit		Primary Nesting Location								Grouped Nesting Location	Nesting habit	
Bird Code[1]	Tropical/ Migrant	Resident	Bank	Ground	Shrub	Tree	Cavity	Reeds	Structure	Floating	Water Nester	Multiple Brood	Nest Parasite
ALFL	1				1								
AMAV				1									
AMBI				1									
AMCO										1	1		
AMCR		1				1							
AMGO					1								
AMRE	1					1							
AMRO						1						1	
AMWI	1			1									
BAIS				1									
BAOR	1					1							
BARS	1								1			1	
BBMA		1				1							
BCCH		1					1						
BHCO						1							1
BLJA		1				1							
BLTE	1									1	1		
BNST				1									
BOGU						1							
BRBL					1	1							
BRTH					1							1	
BUFF							1						
BWTE	1			1									
CANG				1									
CANV										1	1		
CCSP					1							1	
CEDW						1							
CHSP						1						1	
CITE	1			1									
COGR						1							

Bird Code[1]	Tropical/ Migrant	Resident	Bank	Ground	Shrub	Tree	Cavity	Reeds	Structure	Floating	Water Nester	Multiple Brood	Nest Parasite
COLO				1									
CORA		1				1							
COYE					1							1	
DOWO		1					1						
EAGR										1	1		
EAKI	1					1							
EAPH									1			1	
EUST		1					1					1	
FISP				1								1	
FRGU	1									1	1		
GADW				1									
GBHE						1							
GRCA					1							1	
GRSP				1								1	
GWTE				1									
HAWO		1					1						
HOGR										1	1		
HOLA				1									
HOSP		1					1					1	
HOWR							1					1	
KILL				1								1	
LBCU				1									
LCSP				1									
LEFL						1							
LESA	1			1									
LESC				1									
LEYE	1			1									
LISP				1									
MAGO				1									
MALL				1									
MERL						1							
MODO						1						1	

Bird Code[1]	Tropical/ Migrant	Resident	Bank	Ground	Shrub	Tree	Cavity	Reeds	Structure	Floating	Water Nester	Multiple Brood	Nest Parasite
NESP				1									
NOFL		1					1						
NOHA				1									
NOPI	1			1									
NRWS			1										
NSHO				1									
OVEN				1									
PIWO		1					1						
RBGR	1					1						1	
RBGU				1									
RBNU							1						
RCKI						1							
REDH										1	1		1
REVI	1				1								
RNDU				1									
RNEP		1		1									
RTHA						1							
RUBL						1							
RUDU				1									1
RUGR		1		1									
RWBL								1			1	1	
SACR				1									
SAVS				1								1	
SORA	1									1	1	1	
SOSP				1								1	
SPPI				1								1	
SWHA	1					1							
SWSP					1							1	
SWTH	1				1								
TEWA	1			1									
TRES							1						
UPSA	1			1									
VESP				1								1	

Bird Code[1]	Tropical/ Migrant	Resident	Bank	Ground	Shrub	Tree	Cavity	Reeds	Structure	Floating	Water Nester	Multiple Brood	Nest Parasite
WAVI						1							
WEME				1								1	
WILL	1			1									
WIPH	1			1									
WISN	1			1									
WTSP				1									
YEWA	1				1								
YHBL								1			1		

[1]Bird codes according to the American Ornithologists Union standards (American Ornithologists' Union, 1983)

	Primary Habitat										Grouped Primary Habitats			Other
Bird Code[1]	Scrub	Marsh	Lake/ Pond	Open Woodland	Grassland Habitat	Forest	Field	River/ Stream	Shoreline	Any-where	Near Water	Forest Dweller	Field/Scrub	Waterfowl
ALFL	1										0	0	1	0
AMAV									1		1	0	0	0
AMBI		1									1	0	0	0
AMCO			1								1	0	0	1
AMCR										1	0	0	1	0
AMGO							1				0	0	1	0
AMRE				1							0	1	0	0
AMRO										1	0	0	1	0
AMWI			1								1	0	0	1
BAIS					1						0	0	0	0
BAOR				1							0	1	0	0
BARS										1	0	0	1	0
BBMA										1	0	0	1	0
BCCH						1					0	1	0	0
BHCO							1				0	0	1	0
BLJA						1					0	1	0	0
BLTE		1									1	0	0	0
BNST									1		1	0	0	0
BOGU			1								1	0	0	0
BRBL				1							0	1	0	0
BRTH	1										0	0	1	0
BUFF			1								1	0	0	1
BWTE			1								1	0	0	1
CANG		1									1	0	0	1
CANV			1								1	0	0	1
CCSP	1										0	0	1	0
CEDW				1							0	1	0	0
CHSP				1							0	1	0	0
CITE		1									1	0	0	1
COGR				1							0	1	0	0

Bird Code[1]	Scrub	Marsh	Lake/ Pond	Open Woodland	Grassland Habitat	Forest	Field	River/ Stream	Shoreline	Any- where	Near Water	Forest Dweller	Field/Scrub	Waterfowl
COLO			1								1	0	0	1
CORA										1	0	0	1	0
COYE	1										0	0	1	0
DOWO						1					0	1	0	0
EAGR			1								1	0	0	1
EAKI							1				0	0	1	0
EAPH				1							0	1	0	0
EUST										1	0	0	1	0
FISP	1										0	0	1	0
FRGU		1									1	0	0	0
GADW		1									1	0	0	1
GBHE		1									1	0	0	0
GRCA	1										0	0	1	0
GRSP					1						0	0	0	0
GWTE		1									1	0	0	1
HAWO						1					0	1	0	0
HOGR			1								1	0	0	1
HOLA					1						0	0	0	0
HOSP							1				0	0	1	0
HOWR				1							0	1	0	0
KILL							1				0	0	1	0
LBCU					1						0	0	0	0
LCSP		1									1	0	0	0
LEFL				1							0	1	0	0
LESA		1									1	0	0	0
LESC			1								1	0	0	1
LEYE		1									1	0	0	0
LISP	1										0	0	1	0
MAGO									1		1	0	0	0
MALL			1								1	0	0	1
MERL				1							0	1	0	0
MODO										1	0	0	1	0
NESP		1									1	0	0	0

Bird Code[1]	Scrub	Marsh	Lake/ Pond	Open Woodland	Grassland Habitat	Forest	Field	River/ Stream	Shoreline	Any-where	Near Water	Forest Dweller	Field/Scrub	Waterfowl
NOFL				1							0	1	0	0
NOHA					1						0	0	0	0
NOPI			1								1	0	0	1
NRWS								1			1	0	0	0
NSHO		1									1	0	0	1
OVEN						1					0	1	0	0
PIWO						1					0	1	0	0
RBGR						1					0	1	0	0
RBGU			1								1	0	0	0
RBNU						1					0	1	0	0
RCKI						1					0	1	0	0
REDH		1									1	0	0	1
REVI						1					0	1	0	0
RNDU			1								1	0	0	1
RNEP							1				0	0	1	0
RTHA				1							0	1	0	0
RUBL						1					0	1	0	0
RUDU		1									1	0	0	1
RUGR						1					0	1	0	0
RWBL		1									1	0	0	0
SACR		1									1	0	0	0
SAVS					1						0	0	0	0
SORA		1									1	0	0	0
SOSP				1							0	1	0	0
SPPI					1						0	0	0	0
SWHA					1						0	0	0	0
SWSP		1									1	0	0	0
SWTH						1					0	1	0	0
TEWA						1					0	1	0	0
TRES			1								1	0	0	0
UPSA					1						0	0	0	0
VESP					1						0	0	0	0
WAVI				1							0	1	0	0

Bird Code[1]	Scrub	Marsh	Lake/ Pond	Open Woodland	Grassland Habitat	Forest	Field	River/ Stream	Shoreline	Any-where	Near Water	Forest Dweller	Field/Scrub	Waterfowl
WEME					1						0	0	0	0
WILL									1		1	0	0	0
WIPH									1		1	0	0	0
WISN		1									1	0	0	0
WTSP						1					0	1	0	0
YEWA										1	0	0	1	0
YHBL		1									1	0	0	0

[1]Bird codes according to the American Ornithologists Union standards (American Ornithologists' Union, 1983)

Appendix 5. Tested avian metrics for the Parkland IBI, with Spearman rank correlation coefficient and p value for each metric correlation with the Disturbance scores. Significant metrics were included in redundancy analysis.

Metric	Metric Variations[1]	Spearman rho	p
Alder Flycatcher	Total abundance	0.01	0.966
	Relative abundance	0.00	0.994
Specialists - habitat preference[2]	Total abundance	-0.27	0.194
	Proportion (number of individuals/number of species)	-0.27	0.194
	Relative abundance	-0.29	0.171
	Richness	-0.27	0.194
American Coot	Total abundance	-0.06	0.793
	Relative abundance	-0.04	0.856
American Crow	Total abundance	0.02	0.927
	Relative abundance	0.16	0.468
Amphibians - primary diet[2]	Total abundance	-0.06	0.787
	Proportion (number of individuals/number of species)	-0.03	0.901
	Relative abundance	-0.04	0.855
	Richness	-0.02	0.920
American Robin	Total abundance	0.16	0.454
	Relative abundance	0.08	0.701
American Wigeon	Total abundance	0.10	0.649
	Relative abundance	0.12	0.578
Anywhere - habitat preference[2]	Total abundance	-0.19	0.385
	Proportion (number of individuals/number of species)	-0.36	0.089
	Relative abundance	-0.12	0.589
	Richness	0.05	0.813
Aquatic insects - primary diet[2]	Total abundance	0.05	0.807
	Proportion (number of individuals/number of species)	-0.02	0.922
	Relative abundance	0.07	0.731

	Richness	0.09	0.665
Aquatic plants - primary diet[2]	Total abundance	0.13	0.544
	Proportion (number of individuals/number of species)	0.11	0.614
	Relative abundance	0.15	0.488
	Richness	0.17	0.438
Aerial forager - primary feeding habit[2]	Total abundance	0.21	0.315
	Proportion (number of individuals/number of species)	0.22	0.313
	Relative abundance	0.21	0.321
	Richness	0.18	0.404
Baltimore Oriole	Total abundance	-0.17	0.439
	Relative abundance	-0.17	0.439
Barn Swallow	Total abundance	0.18	0.389
	Relative abundance	0.18	0.389
Black-billed Magpie	Total abundance	0.02	0.930
	Relative abundance	0.05	0.811
Black-billed Magpie & Red-winged Blackbird[3]	Total abundance	-0.06	0.786
	Relative abundance	-0.01	0.981
High disturbance indicators (Black-billed Magpie, Red-winged Blackbird, Mallard) [3]	Total abundance	-0.09	0.673
	Relative abundance	-0.04	0.841
Black-capped Chickadee	Total abundance	-0.21	0.314
	Relative abundance	-0.19	0.378
Brown-headed Cowbird	Total abundance	-0.44	0.032
	Relative abundance	-0.44	0.032
Birds - primary diet[2]	Total abundance	-0.20	0.354
	Proportion (number of individuals/number of species)	-0.19	0.368
	Relative abundance	-0.15	0.499
	Richness	-0.14	0.513
Black Tern	Total abundance	0.14	0.528
	Relative abundance	0.14	0.528
Bark gleaner - primary feeding habit[2]	Total abundance	-0.43	0.036

	Proportion (number of individuals/number of species)	-0.43	0.036
	Relative abundance	-0.39	0.057
	Richness	-0.43	0.036
Brown Thrasher	Total abundance	0.05	0.834
Waterfowl indicators (Blue-winged Teal, Northern Shoveler, Redhead, American Coot)[3]	Total abundance	0.20	0.357
	Proportion (number of individuals/number of species)	0.20	0.345
	Relative abundance	0.25	0.235
	Richness	0.20	0.341
Blue-winged Teal	Total abundance	0.17	0.420
	Relative abundance	0.23	0.283
Canada Goose	Total abundance	0.07	0.753
	Relative abundance	0.05	0.820
Canvasback	Total abundance	0.32	0.132
	Relative abundance	0.32	0.132
Carnivore - diet classification[2]	Total abundance	-0.23	0.283
	Proportion (number of individuals/number of species)	-0.41	0.044
	Relative abundance	-0.28	0.190
	Richness	-0.08	0.714
Carrion - primary diet[2]	Total abundance	-0.02	0.935
	Proportion (number of individuals/number of species)	-0.01	0.955
	Relative abundance	0.00	0.998
	Richness	-0.03	0.901
Cavity - primary nesting location[2]	Total abundance	-0.03	0.902
	Proportion (number of individuals/number of species)	-0.04	0.862
	Relative abundance	0.01	0.964
	Richness	-0.01	0.971
Clay-colored Sparrow	Total abundance	-0.15	0.474
	Relative abundance	-0.04	0.843
Cedar Waxwing	Total abundance	-0.17	0.413
	Relative abundance	-0.17	0.413

Chipping Sparrow	Total abundance	-0.33	0.113
Common Loon	Total abundance	-0.26	0.227
	Relative abundance	-0.26	0.227
Common Raven	Total abundance	-0.26	0.219
	Relative abundance	-0.26	0.219
Common Yellowthroat	Total abundance	-0.26	0.213
	Relative abundance	-0.28	0.186
Dabbler - primary feeding habit[2]	Total abundance	0.12	0.573
	Proportion (number of individuals/number of species)	0.12	0.590
	Relative abundance	0.12	0.569
	Richness	0.17	0.437
Downy Woodpecker	Total abundance	-0.26	0.217
Eastern Kingbird	Total abundance	-0.10	0.640
	Relative abundance	-0.10	0.640
European Starling	Total abundance	0.35	0.091
	Relative abundance	0.35	0.091
Non-native species[2]	Total abundance	0.35	0.091
	Proportion (number of individuals/number of species)	0.35	0.091
	Relative abundance	0.35	0.091
	Richness	0.35	0.095
Field - primary habitat[2]	Total abundance	-0.29	0.167
	Proportion (number of individuals/number of species)	-0.29	0.167
	Relative abundance	-0.26	0.216
	Richness	-0.41	0.047
Field and Scrub - primary habitat[2]	Total abundance	-0.24	0.255
	Proportion (number of individuals/number of species)	-0.22	0.294
	Relative abundance	-0.22	0.310
	Richness	-0.19	0.370
Fish - primary diet[2]	Total abundance	-0.19	0.370
	Proportion (number of individuals/number of species)	-0.19	0.370

	Relative abundance	-0.22	0.293
	Richness	-0.20	0.349
Fisher Alpha diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.13	0.557
Foliage gleaner - primary feeding habit[2]	Total abundance	-0.71	0.000
	Proportion (number of individuals/number of species)	-0.57	0.004
	Relative abundance	-0.69	0.000
	Richness	-0.57	0.004
Floating - primary nesting location[2]	Total abundance	-0.02	0.942
	Proportion (number of individuals/number of species)	-0.04	0.853
	Relative abundance	-0.01	0.957
	Richness	-0.03	0.881
Forest and Open Woodland - primary habitat[2]	Total abundance	-0.48	0.018
	Proportion (number of individuals/number of species)	0.06	0.791
	Relative abundance	-0.41	0.047
	Richness	-0.58	0.003
Forest - primary habitat[2]	Total abundance	-0.61	0.002
	Proportion (number of individuals/number of species)	-0.57	0.004
	Relative abundance	-0.59	0.002
	Richness	-0.61	0.002
Fruit - primary diet[2]	Total abundance	-0.42	0.040
	Proportion (number of individuals/number of species)	-0.31	0.142
	Relative abundance	-0.47	0.022
	Richness	-0.49	0.016
Gadwall	Total abundance	-0.15	0.493
	Relative abundance	-0.15	0.497
Grains - primary diet[2]	Total abundance	0.24	0.250
	Proportion (number of individuals/number of species)	0.18	0.399
	Relative abundance	0.27	0.202
	Richness	0.25	0.234
Grassland - primary habitat[2]	Total abundance	0.38	0.068

	Proportion (number of individuals/number of species)	0.36	0.086
	Relative abundance	0.43	0.034
	Richness	0.41	0.047
Gray Catbird	Total abundance	-0.31	0.144
	Relative abundance	-0.31	0.144
Ground - primary nesting location[2]	Total abundance	0.23	0.287
	Proportion (number of individuals/number of species)	0.30	0.160
	Relative abundance	0.33	0.112
	Richness	0.22	0.295
Ground gleaner - primary feeding habit[2]	Total abundance	-0.02	0.913
	Proportion (number of individuals/number of species)	0.12	0.584
	Relative abundance	0.16	0.445
	Richness	-0.04	0.841
Grasshopper Sparrow	Total abundance	0.05	0.834
	Relative abundance	0.05	0.834
Green-winged Teal	Total abundance	0.41	0.047
	Relative abundance	0.42	0.043
Hawking - primary feeding habit[2]	Total abundance	-0.06	0.771
	Proportion (number of individuals/number of species)	-0.08	0.715
	Relative abundance	-0.07	0.752
Herbivore - diet classification[2]	Total abundance	0.08	0.718
	Proportion (number of individuals/number of species)	0.06	0.767
	Relative abundance	0.06	0.785
	Richness	0.07	0.747
Horned grebe	Total abundance	0.15	0.477
	Relative abundance	0.16	0.441
Horned Lark	Total abundance	0.29	0.175
	Relative abundance	0.29	0.175
House Wren	Relative abundance	0.00	0.990
Hover and glean - primary feeding habit[2]	Total abundance	-0.35	0.095

	Proportion (number of individuals/number of species)	-0.37	0.075
	Relative abundance	-0.36	0.088
	Richness	-0.38	0.070
Hawk and aerial pursuit - primary feeding habit[2]	Total abundance	-0.11	0.594
	Proportion (number of individuals/number of species)	-0.11	0.594
	Relative abundance	-0.10	0.632
	Richness	-0.14	0.512
Insectivore - diet classification[2]	Total abundance	-0.22	0.310
	Proportion (number of individuals/number of species)	0.00	0.993
	Relative abundance	-0.14	0.518
	Richness	-0.15	0.482
Insects - primary diet[2]	Total abundance	-0.39	0.057
	Proportion (number of individuals/number of species)	-0.02	0.913
	Relative abundance	-0.23	0.281
	Richness	-0.35	0.098
Inverse Simpson's Diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.26	0.221
Species evenness - diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	0.11	0.593
Jost Shannon diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.24	0.253
Jost Simpson diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.26	0.221
Killdeer	Total abundance	0.25	0.247
	Relative abundance	0.26	0.228
Le Conte's Sparrow	Total abundance	0.10	0.638
	Relative abundance	0.10	0.629
Least Flycatcher	Total abundance	-0.29	0.165
	Relative abundance	-0.28	0.193
Least Sandpiper	Total abundance	0.06	0.777
	Relative abundance	0.06	0.780
Lincoln's Sparrow	Total abundance	-0.14	0.528
	Relative abundance	-0.14	0.528
Lake and pond - primary habitat[2]	Total abundance	0.15	0.485

	Proportion (number of individuals/number of species)	0.10	0.644
	Relative abundance	0.18	0.394
	Richness	0.18	0.412
Grassland low disturbance indicators (Western Meadowlark, Northern Pintail, Baird's Sparrow)[3]	Total abundance	0.10	0.627
	Relative abundance	0.10	0.627
Parkland low disturbance indicators (Red-eyed Vireo, Black-capped Chickadee, Chipping Sparrow, White-throated Sparrow, Red-breasted Nuthatch) [3]	Total abundance	-0.56	0.005
	Proportion (number of individuals/number of species)	-0.57	0.004
	Relative abundance	-0.50	0.013
	Richness	-0.51	0.011
Bark gleaner - primary feeding habit, and Tree - primary nesting location[2]	Total abundance	-0.40	0.051
	Proportion (number of individuals/number of species)	-0.27	0.209
	Relative abundance	-0.36	0.083
	Richness	-0.42	0.042
Marbled Godwit	Total abundance	0.05	0.834
	Relative abundance	0.05	0.834
Mallard	Total abundance	0.04	0.869
	Relative abundance	0.00	0.983
Marsh - primary habitat[2]	Total abundance	0.05	0.811
	Proportion (number of individuals/number of species)	-0.05	0.816
	Relative abundance	0.08	0.701
	Richness	0.11	0.595
Merlin	Total abundance	-0.26	0.227
	Relative abundance	-0.26	0.227
Multiple broods - nesting habit[2]	Total abundance	0.09	0.664
	Proportion (number of individuals/number of species)	0.10	0.650
	Relative abundance	0.32	0.127
	Richness	-0.02	0.913
Mourning Dove	Total abundance	0.20	0.359
	Relative abundance	0.20	0.359
Marsh, lake/pond, Shoreline - primary habitat[2]	Total abundance	0.15	0.490

	Proportion (number of individuals/number of species)	-0.06	0.792
	Relative abundance	0.19	0.375
	Richness	0.19	0.371
Nelson's Sparrow	Total abundance	-0.07	0.736
	Relative abundance	-0.06	0.788
Northern Flicker	Total abundance	0.35	0.089
Northern Shoveler	Total abundance	0.08	0.713
	Relative abundance	0.11	0.615
Nest parasite - nesting habit[2]	Total abundance	-0.18	0.411
	Proportion (number of individuals/number of species)	-0.17	0.423
	Relative abundance	-0.18	0.391
	Richness	-0.18	0.389
Nuts - primary diet[2]	Total abundance	-0.10	0.639
	Proportion (number of individuals/number of species)	-0.09	0.668
	Relative abundance	-0.05	0.810
	Richness	-0.02	0.926
Obligate wetland species[2]	Total abundance	0.18	0.396
	Proportion (number of individuals/number of species)	0.09	0.662
	Relative abundance	0.19	0.362
	Richness	0.15	0.474
Omnivore - diet classification[2]	Total abundance	0.07	0.755
	Proportion (number of individuals/number of species)	0.18	0.399
	Relative abundance	0.34	0.103
	Richness	-0.03	0.872
Open woodland - primary habitat[2]	Total abundance	-0.26	0.215
	Proportion (number of individuals/number of species)	0.00	1.000
	Relative abundance	-0.10	0.636
	Richness	-0.46	0.025
Ovenbird	Total abundance	-0.32	0.132
	Relative abundance	-0.32	0.132

Pileated Woodpecker	Total abundance	-0.35	0.097
	Relative abundance	-0.35	0.097
Plants - primary diet[2]	Total abundance	0.08	0.725
	Proportion (number of individuals/number of species)	0.14	0.523
	Relative abundance	0.17	0.432
	Richness	0.07	0.745
Probes - primary feeding habit[2]	Total abundance	0.05	0.803
	Proportion (number of individuals/number of species)	0.04	0.842
	Relative abundance	0.05	0.804
	Richness	0.11	0.625
Red-breasted Nuthatch	Total abundance	-0.14	0.525
	Relative abundance	-0.11	0.612
Ruby-crowned Kinglet	Total abundance	-0.32	0.132
	Relative abundance	-0.32	0.132
Redhead	Total abundance	0.22	0.300
	Relative abundance	0.22	0.300
Reeds - primary nesting location[2]	Total abundance	0.05	0.830
	Proportion (number of individuals/number of species)	-0.01	0.964
	Relative abundance	0.02	0.938
	Richness	0.09	0.669
Resident - migration habit[2]	Total abundance	0.03	0.896
	Proportion (number of individuals/number of species)	-0.01	0.981
	Relative abundance	0.09	0.670
	Richness	0.00	0.998
Red-eyed Vireo	Total abundance	-0.20	0.359
	Relative abundance	-0.20	0.341
Total avian community species richness/site		-0.14	0.527
Ring-necked Duck	Total abundance	0.11	0.624
	Relative abundance	0.11	0.624
Red-tailed Hawk	Total abundance	-0.01	0.978

	Relative abundance	0.01	0.958
Ruddy Duck	Total abundance	-0.11	0.624
	Relative abundance	-0.11	0.624
Ruffed Grouse	Total abundance	-0.14	0.525
	Relative abundance	-0.17	0.429
Red-winged Blackbird	Total abundance	-0.01	0.971
	Relative abundance	0.00	0.987
High disturbance waterfowl indicators (Red-winged Blackbird, American Coot, Redhead)[3]	Total abundance	0.02	0.938
	Relative abundance	0.04	0.870
Savannah Sparrow	Total abundance	0.22	0.309
	Relative abundance	0.28	0.185
Scrub - primary nesting location[2]	Total abundance	-0.25	0.234
	Proportion (number of individuals/number of species)	-0.15	0.489
	Relative abundance	-0.13	0.560
	Richness	-0.34	0.100
Seeds - primary diet[2]	Total abundance	0.18	0.388
	Proportion (number of individuals/number of species)	0.00	0.994
	Relative abundance	0.10	0.642
	Richness	0.06	0.775
Shannon diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.24	0.253
Stalking and probing - primary feeding habit[2]	Total abundance	0.05	0.803
	Proportion (number of individuals/number of species)	0.04	0.842
	Relative abundance	0.05	0.804
	Richness	0.11	0.625
Shrub - primary nesting location[2]	Total abundance	-0.56	0.004
	Proportion (number of individuals/number of species)	-0.27	0.197
	Relative abundance	-0.43	0.036
	Richness	-0.43	0.037
Shoreline - primary habitat[2]	Total abundance	0.05	0.834
	Proportion (number of individuals/number of species)	0.05	0.834

	Relative abundance	0.05	0.834
	Richness	0.05	0.834
Shrub and tree - primary nesting location[2]	Total abundance	-0.55	0.005
	Proportion (number of individuals/number of species)	-0.19	0.385
	Relative abundance	-0.46	0.022
	Richness	-0.59	0.002
Simpson diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.26	0.221
Small animals - primary diet[2]	Total abundance	-0.18	0.404
	Proportion (number of individuals/number of species)	-0.18	0.404
	Relative abundance	-0.16	0.462
	Richness	-0.18	0.398
Sora	Total abundance	-0.26	0.212
	Relative abundance	-0.25	0.245
Song Sparrow	Total abundance	-0.01	0.976
	Relative abundance	0.04	0.846
Special concern - Federal or Alberta provincial listing as Species-at-Risk[2]	Total abundance	-0.23	0.288
	Proportion (number of individuals/number of species)	-0.23	0.288
	Relative abundance	-0.23	0.288
	Richness	-0.23	0.288
Sprague's Pipit	Total abundance	-0.23	0.288
	Relative abundance	-0.23	0.288
Surface diver - primary feeding habit[2]	Total abundance	0.08	0.697
	Proportion (number of individuals/number of species)	0.05	0.817
	Relative abundance	0.06	0.782
	Richness	0.08	0.700
Structures - primary nesting location[2]	Total abundance	0.18	0.389
	Proportion (number of individuals/number of species)	0.18	0.389
	Relative abundance	0.18	0.389
	Richness	0.17	0.416
Swamp Sparrow	Total abundance	-0.26	0.227

	Relative abundance	-0.26	0.227
Swainson's Thrush	Total abundance	-0.26	0.227
	Relative abundance	-0.26	0.227
Number of individuals/site		-0.14	0.514
Tree - primary nesting location[2]	Total abundance	-0.39	0.060
	Proportion (number of individuals/number of species)	-0.31	0.146
	Relative abundance	-0.33	0.115
	Richness	-0.38	0.065
Tree Swallow	Total abundance	0.21	0.314
	Relative abundance	0.23	0.274
Tropical migrant - migration habit[2]	Total abundance	-0.17	0.432
	Proportion (number of individuals/number of species)	-0.27	0.199
	Relative abundance	-0.29	0.170
	Richness	-0.06	0.767
Unbiased Simpson diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.29	0.169
Vesper Sparrow	Total abundance	0.46	0.024
	Relative abundance	0.46	0.024
Surface diver and dabbler - primary feeding habit[2]	Total abundance	0.11	0.616
	Proportion (number of individuals/number of species)	0.12	0.576
	Relative abundance	0.14	0.526
	Richness	0.14	0.522
Reeds and floating - primary nesting location[2]	Total abundance	0.03	0.880
	Proportion (number of individuals/number of species)	-0.02	0.914
	Relative abundance	0.01	0.971
	Richness	0.03	0.883
Waterfowl species[2]	Total abundance	0.11	0.616
	Proportion (number of individuals/number of species)	0.12	0.576
	Relative abundance	0.14	0.526
	Richness	0.14	0.522
Western Meadowlark	Total abundance	0.10	0.627

	Relative abundance	0.10	0.627
Willet	Total abundance	0.05	0.834
	Relative abundance	0.05	0.834
Wilson's Snipe	Total abundance	0.05	0.834
	Relative abundance	0.05	0.833
White-throated Sparrow	Total abundance	-0.54	0.007
	Relative abundance	-0.53	0.008
Yellow Warbler	Total abundance	-0.44	0.030
	Relative abundance	-0.39	0.058
Yellow-headed Blackbird	Total abundance	0.22	0.301
	Relative abundance	0.22	0.301

[1] For each metric, four variations were calculated. For metrics based on a single species or was composed of three or less grouped species, only total abundance and relative abundance were calculated. Total abundance was the sum of all the individuals for that specific metric at each site. Relative abundance was the sum of the total number of individuals for the specific metric divided by all the individuals counted at the site. For the metrics that were based on a group of species, from trait characteristics or indicator species, the proportion and richness were calculated in addition to the total and relative abundance. For the proportion, this variation was calculated for each metric by summing all the number of individuals for the specified metric and dividing by the number of species for the specified metric. For the richness, this variation was calculated by summing the number of species for the specified metric.

[2]Trait-based metric based on species traits as outlined in Appendix 4.

[3]Species indicators grouped based on analyses by Polan (2016).

[4]Diversity indices were calculated based on referenced methods for each site visited.

Appendix 6. Pearson correlation coefficient matrix for redundancy analysis for Parkland IBI. Methods for selection of metrics included in IBI explained in text. Metric variants depicted (TA = total abundance, RA = relative abundance, Sp = richness, PR = proportion). Species codes according to the American Ornithologists Union standards (American Ornithologists' Union, 1983).

	BHCO_RA	Bark Gleaner_Sp	Carnivore_PR	Field_Scrub_TA	Foliage Gleaner_RA	Forest and Open Woodland_Sp	Forest_habitat_Sp	Fruit_diet_Sp	Grassland habitat_RA	GWTE_RA	Parkland low disturbance indicators_PR	Bark Gleaners plus Tree nester_Sp
BHCO_RA												
Bark Gleaner_Sp	0.86											
Carnivore_PR	0.84	0.76										
Field_Scrub_TA	0.85	0.81	0.85									
Foliage Gleaner_RA	0.88	0.87	0.90	0.81								
Forest and Open Woodland_Sp	0.83	0.89	0.87	0.82	0.96							
Forest_habitat_Sp	0.84	0.91	0.79	0.77	0.95	0.95						
Fruit_diet_Sp	0.81	0.80	0.87	0.79	0.91	0.88	0.87					
Grassland habitat_RA	0.52	0.43	0.46	0.47	0.49	0.38	0.40	0.41				
GWTE_RA	0.77	0.72	0.66	0.71	0.71	0.71	0.71	0.67	0.44			
Parkland low disturbance indicators_PR	0.84	0.90	0.77	0.83	0.92	0.93	0.96	0.85	0.48	0.72		
Bark Gleaners plus Tree nester_Sp	0.86	0.90	0.81	0.82	0.84	0.87	0.82	0.84	0.41	0.78	0.83	
Open Woodland_Sp	0.80	0.84	0.89	0.84	0.90	0.96	0.85	0.85	0.44	0.70	0.87	0.88
Shrub_nesting_Sp	0.76	0.67	0.75	0.76	0.80	0.75	0.74	0.72	0.35	0.73	0.72	0.62
Shrub plus Tree nesters_Sp	0.91	0.84	0.87	0.88	0.87	0.88	0.82	0.84	0.37	0.83	0.83	0.92
VESP_RA	0.78	0.72	0.73	0.66	0.75	0.73	0.72	0.72	0.65	0.71	0.72	0.75
WTSP_RA	0.80	0.79	0.75	0.72	0.90	0.90	0.92	0.82	0.50	0.75	0.90	0.75
YEWA_TA	0.86	0.77	0.94	0.85	0.88	0.82	0.77	0.83	0.60	0.69	0.77	0.81

	Open Woodland_Sp	Shrub_nesting_Sp	Shrub plus Tree nesters_Sp	VESP_RA	WTSP_RA	YEWA_TA
BHCO_RA						
Bark Gleaner_Sp						
Carnivore_PR						
Field_Scrub_TA						
Foliage Gleaner_RA						
Forest and Open Woodland_Sp						
Forest_habitat_Sp						
Fruit_diet_Sp						
Grassland habitat_RA						
GWTE_RA						
Parkland low disturbance indicators_PR						
Bark Gleaners plus Tree nester_Sp						
Open Woodland_Sp						
Shrub_nesting_Sp	0.72					
Shrub plus Tree nesters_Sp	0.89	0.83				
VESP_RA	0.75	0.58	0.74			
WTSP_RA	0.84	0.73	0.77	0.76		
YEWA_TA	0.83	0.75	0.84	0.71	0.75	

Appendix 7. Tested avian metrics for the Grassland IBI, with Spearman rank correlation coefficient and p value for each metric correlation with the Disturbance scores. Significant metrics were included in redundancy analysis.

Metric	Metric Variations	Spearman rho	p
Specialists - habitat preference[2]	Total abundance	-0.05	0.830
	Proportion (number of individuals/number of species)	-0.04	0.839
	Relative abundance	0.03	0.878
	Richness	-0.15	0.494
American Avocet	Total abundance	-0.14	0.527
	Relative abundance	-0.14	0.527
American Coot	Total abundance	-0.15	0.473
	Relative abundance	-0.13	0.556
American Crow	Total abundance	0.22	0.308
	Relative abundance	0.26	0.218
Amphibians - primary diet[2]	Total abundance	0.07	0.763
	Proportion (number of individuals/number of species)	0.00	0.991
	Relative abundance	0.08	0.699
	Richness	0.06	0.764
American Robin	Total abundance	-0.23	0.288
	Relative abundance	-0.23	0.288
American Wigeon	Total abundance	-0.14	0.527
	Relative abundance	-0.14	0.527
Anywhere - habitat preference[2]	Total abundance	0.09	0.668
	Proportion (number of individuals/number of species)	0.09	0.677
	Relative abundance	0.08	0.696
	Richness	0.10	0.630
Aquatic insects - primary diet[2]	Total abundance	-0.10	0.632
	Proportion (number of individuals/number of species)	-0.18	0.391

	Relative abundance	-0.13	0.554
	Richness	-0.04	0.853
Aquatic plants - primary diet[2]	Total abundance	-0.16	0.460
	Proportion (number of individuals/number of species)	-0.19	0.385
	Relative abundance	-0.16	0.466
	Richness	-0.04	0.869
Aerial forager - primary feeding habit[2]	Total abundance	-0.11	0.612
	Proportion (number of individuals/number of species)	-0.11	0.612
	Relative abundance	-0.10	0.642
	Richness	-0.11	0.612
Baird's Sparrow	Total abundance	-0.38	0.068
	Relative abundance	-0.32	0.128
Baltimore Oriole	Total abundance	-0.23	0.288
	Relative abundance	-0.23	0.288
Barn Swallow	Total abundance	0.08	0.726
	Relative abundance	0.08	0.726
Black-billed Magpie	Total abundance	0.17	0.438
	Relative abundance	0.17	0.438
Black-billed Magpie & Red-winged Blackbird[3]	Total abundance	0.17	0.418
	Relative abundance	0.34	0.100
High disturbance indicators (Black-billed Magpie, Red-winged Blackbird, Mallard)[3]	Total abundance	0.33	0.114
	Relative abundance	0.43	0.038
Brown-headed Cowbird	Total abundance	-0.13	0.541
	Relative abundance	-0.10	0.657
Birds - primary diet[2]	Total abundance	0.12	0.563
	Proportion (number of individuals/number of species)	0.12	0.563
	Relative abundance	0.13	0.538
	Richness	0.13	0.537
Brewer's Blackbird	Total abundance	-0.09	0.673
	Relative abundance	-0.08	0.698

Waterfowl indicators (Blue-winged Teal, Northern Shoveler, Redhead, American Coot)[3]	Total abundance	-0.27	0.203
	Proportion (number of individuals/number of species)	-0.25	0.237
	Relative abundance	-0.25	0.241
	Richness	-0.21	0.321
Blue-winged Teal	Total abundance	-0.31	0.146
	Relative abundance	-0.29	0.170
Canada Goose	Total abundance	0.10	0.646
	Relative abundance	0.11	0.596
Carnivore - diet classification[2]	Total abundance	-0.04	0.864
	Proportion (number of individuals/number of species)	-0.15	0.490
	Relative abundance	0.16	0.453
	Richness	0.07	0.746
Carrion - primary diet[2]	Total abundance	-0.02	0.919
	Proportion (number of individuals/number of species)	-0.02	0.919
	Relative abundance	-0.03	0.879
	Richness	-0.02	0.919
Cavity - primary nesting location[2]	Total abundance	-0.23	0.288
	Proportion (number of individuals/number of species)	-0.23	0.288
	Relative abundance	-0.23	0.288
	Richness	-0.23	0.288
Clay-colored Sparrow	Total abundance	-0.14	0.506
	Relative abundance	-0.12	0.587
Common Grackle	Total abundance	-0.17	0.438
	Relative abundance	-0.17	0.438
Common Raven	Total abundance	-0.20	0.358
	Relative abundance	-0.20	0.358
Dabbler - primary feeding habit[2]	Total abundance	-0.20	0.343
	Proportion (number of individuals/number of species)	-0.18	0.403
	Relative abundance	-0.18	0.412
	Richness	-0.09	0.669

Non-native species[2]	Total abundance	0.04	0.851
	Proportion (number of individuals/number of species)	0.04	0.851
	Relative abundance	0.08	0.724
	Richness	0.04	0.851
Field - primary habitat[2]	Total abundance	0.13	0.558
	Proportion (number of individuals/number of species)	0.17	0.429
	Relative abundance	0.20	0.353
	Richness	0.04	0.850
Field and Scrub - primary habitat[2]	Total abundance	0.03	0.873
	Proportion (number of individuals/number of species)	0.09	0.676
	Relative abundance	0.05	0.811
	Richness	0.14	0.527
Fish - primary diet[2]	Total abundance	-0.03	0.899
	Proportion (number of individuals/number of species)	-0.03	0.899
	Relative abundance	-0.05	0.806
	Richness	-0.03	0.899
Fisher Alpha diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	0.28	0.193
Foliage gleaner - primary feeding habit[2]	Total abundance	-0.23	0.288
	Proportion (number of individuals/number of species)	-0.23	0.288
	Relative abundance	-0.23	0.288
	Richness	-0.23	0.288
Floating - primary nesting location[2]	Total abundance	0.08	0.698
	Proportion (number of individuals/number of species)	0.08	0.698
	Relative abundance	0.13	0.560
	Richness	0.08	0.698
Forest and Open Woodland - primary habitat[2]	Total abundance	-0.12	0.563
	Proportion (number of individuals/number of species)	-0.08	0.704
	Relative abundance	-0.08	0.693
	Richness	-0.16	0.448
Forest - primary habitat[2]	Total abundance	-0.17	0.438

	Proportion (number of individuals/number of species)	-0.17	0.438
	Relative abundance	-0.17	0.438
	Richness	-0.17	0.438
Fruit - primary diet[2]	Total abundance	-0.02	0.940
	Proportion (number of individuals/number of species)	-0.02	0.940
	Relative abundance	-0.02	0.934
	Richness	-0.02	0.940
Gadwall	Total abundance	-0.18	0.398
	Relative abundance	-0.09	0.672
Grains - primary diet[2]	Total abundance	-0.19	0.382
	Proportion (number of individuals/number of species)	-0.20	0.357
	Relative abundance	0.31	0.140
	Richness	0.07	0.757
Grassland - primary habitat[2]	Total abundance	-0.17	0.437
	Proportion (number of individuals/number of species)	-0.28	0.178
	Relative abundance	0.02	0.916
	Richness	-0.03	0.896
Ground - primary nesting location[2]	Total abundance	-0.30	0.154
	Proportion (number of individuals/number of species)	-0.62	0.001
	Relative abundance	-0.34	0.101
	Richness	0.06	0.788
Ground gleaner - primary feeding habit[2]	Total abundance	-0.13	0.532
	Proportion (number of individuals/number of species)	-0.13	0.560
	Relative abundance	0.11	0.619
	Richness	-0.07	0.741
Grasshopper Sparrow	Total abundance	-0.31	0.136
	Relative abundance	-0.32	0.134
Green-winged Teal	Total abundance	0.02	0.939
	Relative abundance	0.11	0.598
Herbivore - diet classification[2]	Total abundance	-0.16	0.449

	Proportion (number of individuals/number of species)	-0.20	0.349
	Relative abundance	-0.14	0.503
	Richness	-0.15	0.475
Horned Lark	Total abundance	0.36	0.083
	Relative abundance	0.37	0.071
House Sparrow	Total abundance	-0.23	0.288
	Relative abundance	-0.23	0.288
House Wren	Total abundance	-0.23	0.288
	Relative abundance	-0.23	0.288
Insectivore - diet classification[2]	Total abundance	-0.35	0.096
	Proportion (number of individuals/number of species)	-0.27	0.202
	Relative abundance	-0.20	0.342
	Richness	-0.16	0.463
Insects - primary diet[2]	Total abundance	-0.07	0.758
	Proportion (number of individuals/number of species)	-0.19	0.366
	Relative abundance	0.13	0.550
	Richness	0.03	0.887
Inverse Simpson's Diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.14	0.515
Species evenness - diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	0.07	0.751
Jost Shannon diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.06	0.791
Jost Simpson diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.14	0.515
Killdeer	Total abundance	0.21	0.327
	Relative abundance	0.21	0.327
Le Conte's Sparrow	Total abundance	0.30	0.153
	Relative abundance	0.29	0.173
Least Flycatcher	Total abundance	-0.06	0.786
	Relative abundance	-0.06	0.786
Least Sandpiper	Total abundance	0.32	0.132
	Relative abundance	0.32	0.132
Lincoln's Sparrow	Total abundance	0.05	0.801

	Relative abundance	0.07	0.733
Lake and pond - primary habitat[2]	Total abundance	-0.20	0.354
	Proportion (number of individuals/number of species)	-0.15	0.470
	Relative abundance	-0.14	0.508
	Richness	-0.04	0.850
Grassland low disturbance indicators (Western Meadowlark, Northern Pintail, Baird's Sparrow)[3]	Total abundance	-0.38	0.064
	Relative abundance	-0.32	0.134
Parkland low disturbance indicators (Red-eyed Vireo, Black-capped Chickadee, Chipping Sparrow, White-throated Sparrow, Red-breasted Nuthatch)[3]	Total abundance	-0.01	0.969
	Proportion (number of individuals/number of species)	-0.01	0.945
	Relative abundance	0.03	0.883
	Richness	-0.02	0.916
Marbled Godwit	Total abundance	-0.08	0.717
	Relative abundance	0.01	0.968
Mallard	Total abundance	0.46	0.025
	Relative abundance	0.47	0.021
Marsh - primary habitat[2]	Total abundance	-0.01	0.976
	Proportion (number of individuals/number of species)	-0.06	0.791
	Relative abundance	0.27	0.202
	Richness	0.00	0.988
Multiple broods - nesting habit[2]	Total abundance	-0.26	0.221
	Proportion (number of individuals/number of species)	-0.25	0.248
	Relative abundance	0.00	0.992
	Richness	-0.06	0.780
Mourning Dove	Total abundance	-0.23	0.288
	Relative abundance	-0.23	0.288
Marsh, lake/pond, Shoreline - primary habitat[2]	Total abundance	-0.11	0.594
	Proportion (number of individuals/number of species)	-0.24	0.262
	Relative abundance	0.03	0.888
	Richness	-0.03	0.893
Nelson's Sparrow	Total abundance	-0.33	0.119

	Relative abundance	-0.33	0.113
Northern Pintail	Total abundance	-0.33	0.110
	Relative abundance	-0.33	0.116
Northern Shoveler	Total abundance	-0.33	0.115
	Relative abundance	-0.31	0.139
Nest parasite - nesting habit[2]	Total abundance	-0.06	0.770
	Proportion (number of individuals/number of species)	-0.06	0.770
	Relative abundance	-0.02	0.917
	Richness	0.01	0.976
Nuts - primary diet[2]	Total abundance	-0.13	0.534
	Proportion (number of individuals/number of species)	-0.14	0.502
	Relative abundance	0.00	0.994
	Richness	0.02	0.944
Obligate wetland species[2]	Total abundance	-0.12	0.578
	Proportion (number of individuals/number of species)	-0.23	0.286
	Relative abundance	-0.05	0.813
	Richness	0.00	0.998
Omnivore - diet classification[2]	Total abundance	-0.40	0.050
	Proportion (number of individuals/number of species)	-0.36	0.087
	Relative abundance	-0.06	0.778
	Richness	-0.15	0.497
Open woodland - primary habitat[2]	Total abundance	-0.10	0.659
	Proportion (number of individuals/number of species)	-0.07	0.736
	Relative abundance	-0.06	0.780
	Richness	-0.14	0.520
Plants - primary diet[2]	Total abundance	0.19	0.377
	Proportion (number of individuals/number of species)	0.22	0.303
	Relative abundance	0.20	0.351
	Richness	0.13	0.541
Probes - primary feeding habit[2]	Total abundance	0.02	0.935

	Proportion (number of individuals/number of species)	-0.11	0.608
	Relative abundance	0.15	0.476
	Richness	0.16	0.455
Ring-billed Gull	Total abundance	0.32	0.132
	Relative abundance	0.32	0.132
Redhead	Total abundance	0.20	0.358
	Relative abundance	0.20	0.358
Reeds - primary nesting location[2]	Total abundance	0.17	0.413
	Proportion (number of individuals/number of species)	0.12	0.591
	Relative abundance	0.32	0.133
	Richness	0.22	0.291
Resident - migration habit[2]	Total abundance	0.09	0.667
	Proportion (number of individuals/number of species)	0.06	0.764
	Relative abundance	0.09	0.660
	Richness	0.09	0.660
Total avian community species richness/site		-0.09	0.667
Ring-necked Pheasant	Total abundance	0.18	0.394
	Relative abundance	0.20	0.343
Rusty Blackbird	Total abundance	-0.17	0.438
	Relative abundance	-0.17	0.438
Red-winged Blackbird	Total abundance	0.16	0.469
	Relative abundance	0.31	0.147
High disturbance waterfowl indicators (Red-winged Blackbird, American Coot, Redhead)[3]	Total abundance	0.14	0.518
	Relative abundance	0.28	0.191
Savannah Sparrow	Total abundance	-0.10	0.635
	Relative abundance	-0.02	0.942
Scrub - primary nesting location[2]	Total abundance	-0.14	0.506
	Proportion (number of individuals/number of species)	-0.14	0.506
	Relative abundance	-0.12	0.587
	Richness	-0.18	0.407

Seeds - primary diet[2]	Total abundance	-0.37	0.071
	Proportion (number of individuals/number of species)	-0.43	0.035
	Relative abundance	-0.06	0.786
	Richness	-0.11	0.600
Shannon diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.06	0.791
Stalking and probing - primary feeding habit[2]	Total abundance	0.02	0.935
	Proportion (number of individuals/number of species)	-0.11	0.608
	Relative abundance	0.15	0.476
	Richness	0.16	0.455
Shrub - primary nesting location[2]	Total abundance	-0.13	0.532
	Proportion (number of individuals/number of species)	-0.10	0.649
	Relative abundance	-0.11	0.612
	Richness	-0.31	0.146
Shoreline - primary habitat[2]	Total abundance	-0.14	0.508
	Proportion (number of individuals/number of species)	-0.16	0.449
	Relative abundance	-0.06	0.774
	Richness	0.00	0.984
Shrub and tree - primary nesting location[2]	Total abundance	-0.13	0.551
	Proportion (number of individuals/number of species)	-0.07	0.746
	Relative abundance	-0.09	0.676
	Richness	-0.15	0.477
Simpson diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.14	0.515
Small animals - primary diet[2]	Total abundance	0.09	0.685
	Proportion (number of individuals/number of species)	0.09	0.685
	Relative abundance	0.07	0.739
	Richness	0.09	0.685
Sora	Total abundance	0.27	0.199
	Relative abundance	0.27	0.199
Song Sparrow	Total abundance	0.05	0.831
	Relative abundance	0.09	0.690

Special concern - Federal or Alberta provincial listing as Species-at-Risk[2]	Total abundance	-0.25	0.241
	Proportion (number of individuals/number of species)	-0.27	0.205
	Relative abundance	-0.23	0.274
	Richness	-0.11	0.615
Sprague's Pipit	Total abundance	-0.34	0.099
	Relative abundance	-0.31	0.134
Surface diver - primary feeding habit[2]	Total abundance	0.07	0.744
	Proportion (number of individuals/number of species)	0.05	0.801
	Relative abundance	0.08	0.703
	Richness	0.06	0.795
Structures - primary nesting location[2]	Total abundance	0.08	0.726
	Proportion (number of individuals/number of species)	0.08	0.726
	Relative abundance	0.08	0.726
	Richness	0.08	0.726
Number of individuals/site		-0.33	0.114
Tree - primary nesting location[2]	Total abundance	-0.01	0.969
	Proportion (number of individuals/number of species)	-0.01	0.945
	Relative abundance	0.03	0.883
	Richness	-0.02	0.916
Tree Swallow	Total abundance	-0.23	0.288
	Relative abundance	-0.23	0.288
Tropical migrant - migration habit[2]	Total abundance	-0.27	0.202
	Proportion (number of individuals/number of species)	-0.33	0.112
	Relative abundance	-0.22	0.296
	Richness	-0.15	0.473
Unbiased Simpson diversity index[4]		-0.06	0.768
Upland Sandpiper	Total abundance	0.02	0.933
	Relative abundance	0.01	0.952
Vesper Sparrow	Total abundance	0.42	0.043
	Relative abundance	0.40	0.051

Surface diver and dabbler - primary feeding habit[2]	Total abundance	-0.18	0.402
	Proportion (number of individuals/number of species)	-0.21	0.319
	Relative abundance	-0.15	0.487
	Richness	-0.06	0.794
Reeds and floating - primary nesting location[2]	Total abundance	0.18	0.401
	Proportion (number of individuals/number of species)	0.12	0.567
	Relative abundance	0.32	0.128
	Richness	0.16	0.456
Waterfowl species[2]	Total abundance	-0.16	0.460
	Proportion (number of individuals/number of species)	-0.19	0.385
	Relative abundance	-0.16	0.466
	Richness	-0.04	0.869
Western Meadowlark	Total abundance	-0.22	0.307
	Relative abundance	-0.04	0.840
Willet	Total abundance	-0.02	0.924
	Relative abundance	0.03	0.875
Wilson's Phalarope	Total abundance	-0.17	0.433
	Relative abundance	-0.14	0.507
Wilson's Snipe	Total abundance	0.14	0.513
	Relative abundance	0.12	0.582
Yellow Warbler	Total abundance	-0.23	0.288
	Relative abundance	-0.23	0.288
Yellow-headed Blackbird	Total abundance	0.27	0.199
	Relative abundance	0.27	0.199

[1] For each metric, four variations were calculated. For metrics based on a single species or was composed of three or less grouped species, only total abundance and relative abundance were calculated. Total abundance was the sum of all individuals for that specific metric at each site. Relative abundance was the sum of the total number of individuals for the specific metric divided by all the individuals counted at the site. For the metrics that were based on a group of species, from trait characteristics or indicator species, the proportion and richness were calculated in addition to the total and relative abundance. For the proportion, this variation was

calculated for each metric by summing all the number of individuals for the specified metrics and dividing by the number of species for the specified metric. For the richness, this variation was calculated by summing the number of species for the specified metric.

[2]Trait-based metric based on species traits as outlined in Appendix 4.

[3]Species indicators grouped based on analyses by Polan (2016).

[4]Diversity indices were calculated based on referenced methods for each site visited.

Appendix 8. Pearson correlation coefficient matrix for redundancy analysis for Grassland IBI. Methods for selection of metrics included in IBI explained in text. Metric variants depicted (TA = total abundance, RA = relative abundance, Sp = richness, PR = proportion). Species codes according to the American Ornithologists Union standards (American Ornithologists' Union, 1983).

	High disturbance indicators_RA	Ground nesting_PR	Grassland low disturbance indicators_Sp	MALL_RA	Seeds diet_PR	VESP_TA
High disturbance indicators_RA						
Ground nesting_PR	0.32					
Grassland low disturbance indicators_Sp	0.40	0.78				
MALL_RA	0.66	0.56	0.45			
Seeds diet_PR	0.20	0.93	0.73	0.47		
VESP_TA	0.49	0.73	0.57	0.70	0.66	

Appendix 9. Tested avian metrics for the Both Regions IBI, with Spearman rank correlation coefficient and p value for each metric correlation with the Disturbance scores. Significant metrics were included in redundancy analysis.

Metric	Metric Variations	Spearman rho	p
Alder Flycatcher	Total abundance	-0.02	0.917
	Relative abundance	-0.02	0.894
Specialists - habitat preference[2]	Total abundance	-0.08	0.612
	Proportion (number of individuals/number of species)	-0.08	0.601
	Relative abundance	-0.05	0.716
	Richness	-0.11	0.460
American Avocet	Total abundance	-0.06	0.696
	Relative abundance	-0.06	0.696
American Coot	Total abundance	-0.07	0.618
	Relative abundance	-0.06	0.705
American Crow	Total abundance	0.11	0.464
	Relative abundance	0.18	0.212
Amphibians - primary diet[2]	Total abundance	0.02	0.916
	Proportion (number of individuals/number of species)	-0.02	0.881
	Relative abundance	0.04	0.794
	Richness	0.03	0.851
American Robin	Total abundance	-0.02	0.906
	Relative abundance	-0.04	0.767
American Wigeon	Total abundance	-0.01	0.960
	Relative abundance	0.00	0.986
Anywhere - habitat preference[2]	Total abundance	-0.11	0.477
	Proportion (number of individuals/number of species)	-0.16	0.285
	Relative abundance	-0.08	0.592

	Richness	-0.01	0.939
Aquatic insects - primary diet[2]	Total abundance	0.06	0.696
	Proportion (number of individuals/number of species)	-0.06	0.687
	Relative abundance	0.09	0.545
	Richness	0.07	0.655
Aquatic plants - primary diet[2]	Total abundance	0.09	0.531
	Proportion (number of individuals/number of species)	-0.01	0.938
	Relative abundance	0.13	0.365
	Richness	0.15	0.305
Aerial forager - primary feeding habit[2]	Total abundance	0.06	0.675
	Proportion (number of individuals/number of species)	0.06	0.672
	Relative abundance	0.06	0.664
	Richness	0.04	0.780
Baird's Sparrow	Total abundance	-0.16	0.274
	Relative abundance	-0.14	0.326
Baltimore Oriole	Total abundance	-0.19	0.200
	Relative abundance	-0.19	0.202
Barn Swallow	Total abundance	0.10	0.494
	Relative abundance	0.10	0.494
Black-billed Magpie	Total abundance	0.01	0.936
	Relative abundance	0.02	0.870
Black-billed Magpie & Red-winged Blackbird[3]	Total abundance	0.06	0.701
	Relative abundance	0.17	0.244
High disturbance indicators (Black-billed Magpie, Red-winged Blackbird, Mallard) [3]	Total abundance	0.10	0.500
	Relative abundance	0.20	0.172
Black-capped Chickadee	Total abundance	-0.21	0.156
	Relative abundance	-0.20	0.175
Brown-headed Cowbird	Total abundance	-0.23	0.121
	Relative abundance	-0.21	0.144
Birds - primary diet[2]	Total abundance	-0.06	0.669

	Proportion (number of individuals/number of species)	-0.06	0.692
	Relative abundance	-0.04	0.773
	Richness	-0.03	0.828
Black Tern	Total abundance	0.13	0.372
	Relative abundance	0.13	0.372
Brewer's Blackbird	Total abundance	-0.02	0.906
	Relative abundance	-0.02	0.918
Bark gleaner - primary feeding habit[2]	Total abundance	-0.34	0.019
	Proportion (number of individuals/number of species)	-0.34	0.019
	Relative abundance	-0.32	0.025
	Richness	-0.34	0.019
Waterfowl indicators (Blue-winged Teal, Northern Shoveler, Redhead, American Coot)[3]	Total abundance	0.01	0.934
	Proportion (number of individuals/number of species)	0.03	0.858
	Relative abundance	0.04	0.764
	Richness	0.04	0.771
Blue-winged Teal	Total abundance	-0.02	0.898
	Relative abundance	0.00	0.987
Canada Goose	Total abundance	0.05	0.722
	Relative abundance	0.05	0.726
Canvasback	Total abundance	0.23	0.122
	Relative abundance	0.23	0.122
Carnivore - diet classification[2]	Total abundance	-0.16	0.272
	Proportion (number of individuals/number of species)	-0.27	0.061
	Relative abundance	-0.12	0.407
	Richness	-0.04	0.766
Carrion - primary diet[2]	Total abundance	-0.04	0.805
	Proportion (number of individuals/number of species)	-0.03	0.816
	Relative abundance	-0.04	0.782
	Richness	-0.04	0.770
Cavity - primary nesting location[2]	Total abundance	-0.11	0.452

	Proportion (number of individuals/number of species)	-0.11	0.460
	Relative abundance	-0.10	0.508
	Richness	-0.11	0.459
Clay-colored Sparrow	Total abundance	-0.16	0.290
	Relative abundance	-0.10	0.484
Cedar Waxwing	Total abundance	-0.19	0.199
	Relative abundance	-0.19	0.199
Chipping Sparrow	Total abundance	-0.31	0.033
Common Grackle	Total abundance	-0.07	0.644
	Relative abundance	-0.07	0.644
Common Loon	Total abundance	-0.22	0.140
	Relative abundance	-0.22	0.140
Common Raven	Total abundance	-0.25	0.091
	Relative abundance	-0.25	0.092
Common Yellowthroat	Total abundance	-0.21	0.153
	Relative abundance	-0.22	0.141
Dabbler - primary feeding habit[2]	Total abundance	0.07	0.638
	Proportion (number of individuals/number of species)	0.00	1.000
	Relative abundance	0.10	0.499
	Richness	0.12	0.420
Downy Woodpecker	Total abundance	-0.23	0.123
Eastern Kingbird	Total abundance	-0.07	0.657
	Relative abundance	-0.07	0.657
European Starling	Total abundance	0.26	0.069
	Relative abundance	0.26	0.069
Non-native species[2]	Total abundance	0.22	0.127
	Proportion (number of individuals/number of species)	0.22	0.127
	Relative abundance	0.24	0.107
	Richness	0.22	0.140
Field - primary habitat[2]	Total abundance	-0.05	0.731

	Proportion (number of individuals/number of species)	-0.05	0.747
	Relative abundance	0.00	0.991
	Richness	0.03	0.830
Field and Scrub - primary habitat[2]	Total abundance	-0.19	0.206
	Proportion (number of individuals/number of species)	-0.15	0.308
	Relative abundance	-0.11	0.452
	Richness	-0.11	0.437
Fish - primary diet[2]	Total abundance	-0.15	0.312
	Proportion (number of individuals/number of species)	-0.15	0.312
	Relative abundance	-0.17	0.244
	Richness	-0.15	0.324
Fisher Alpha diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	0.07	0.635
Foliage gleaner - primary feeding habit[2]	Total abundance	-0.39	0.006
	Proportion (number of individuals/number of species)	-0.35	0.015
	Relative abundance	-0.39	0.006
	Richness	-0.35	0.015
Floating - primary nesting location[2]	Total abundance	0.00	0.981
	Proportion (number of individuals/number of species)	0.00	0.994
	Relative abundance	0.01	0.922
	Richness	0.00	0.994
Forest and Open Woodland - primary habitat[2]	Total abundance	-0.28	0.058
	Proportion (number of individuals/number of species)	-0.05	0.758
	Relative abundance	-0.23	0.122
	Richness	-0.33	0.020
Forest - primary habitat[2]	Total abundance	-0.44	0.002
	Proportion (number of individuals/number of species)	-0.43	0.002
	Relative abundance	-0.44	0.002
	Richness	-0.44	0.002
Fruit - primary diet[2]	Total abundance	-0.32	0.028
	Proportion (number of individuals/number of species)	-0.27	0.063

	Relative abundance	-0.33	0.024
	Richness	-0.32	0.025
Gadwall	Total abundance	-0.12	0.434
	Relative abundance	-0.08	0.609
Grains - primary diet[2]	Total abundance	0.08	0.591
	Proportion (number of individuals/number of species)	0.05	0.751
	Relative abundance	0.23	0.121
	Richness	0.21	0.152
Grassland - primary habitat[2]	Total abundance	0.17	0.256
	Proportion (number of individuals/number of species)	0.13	0.370
	Relative abundance	0.26	0.070
	Richness	0.19	0.207
Gray Catbird	Total abundance	-0.26	0.071
	Relative abundance	-0.26	0.071
Ground - primary nesting location[2]	Total abundance	0.03	0.855
	Proportion (number of individuals/number of species)	-0.08	0.575
	Relative abundance	0.11	0.444
	Richness	0.16	0.284
Ground gleaner - primary feeding habit[2]	Total abundance	-0.11	0.467
	Proportion (number of individuals/number of species)	-0.04	0.778
	Relative abundance	0.16	0.263
	Richness	-0.03	0.858
Grasshopper Sparrow	Total abundance	-0.13	0.389
	Relative abundance	-0.13	0.379
Green-winged Teal	Total abundance	0.24	0.099
	Relative abundance	0.28	0.052
Hawking - primary feeding habit[2]	Total abundance	-0.05	0.715
	Proportion (number of individuals/number of species)	-0.06	0.677
	Relative abundance	-0.06	0.699
Herbivore - diet classification[2]	Total abundance	-0.03	0.840

	Proportion (number of individuals/number of species)	-0.06	0.708
	Relative abundance	-0.03	0.849
	Richness	-0.02	0.898
Horned grebe	Total abundance	0.08	0.611
	Relative abundance	0.08	0.587
Horned Lark	Total abundance	0.28	0.056
	Relative abundance	0.28	0.054
House Sparrow	Total abundance	-0.11	0.454
	Relative abundance	-0.11	0.454
House Wren	Total abundance	-0.03	0.844
	Relative abundance	-0.03	0.825
Hover and glean - primary feeding habit[2]	Total abundance	-0.28	0.055
	Proportion (number of individuals/number of species)	-0.28	0.050
	Relative abundance	-0.28	0.052
	Richness	-0.29	0.049
Hawk and aerial pursuit - primary feeding habit[2]	Total abundance	-0.12	0.421
	Proportion (number of individuals/number of species)	-0.12	0.421
	Relative abundance	-0.11	0.437
	Richness	-0.13	0.377
Insectivore - diet classification[2]	Total abundance	-0.25	0.088
	Proportion (number of individuals/number of species)	-0.10	0.504
	Relative abundance	-0.15	0.322
	Richness	-0.17	0.261
Insects - primary diet[2]	Total abundance	-0.24	0.096
	Proportion (number of individuals/number of species)	-0.13	0.382
	Relative abundance	-0.16	0.288
	Richness	-0.20	0.181
Inverse Simpson's Diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.19	0.197
Species evenness - diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	0.08	0.567
Jost Shannon diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.15	0.318

Jost Simpson diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.19	0.197
Killdeer	Total abundance	0.24	0.100
	Relative abundance	0.24	0.096
Long Billed Curlew	Total abundance	0.20	0.169
	Relative abundance	0.20	0.178
Le Conte's Sparrow	Total abundance	0.03	0.865
	Relative abundance	0.03	0.865
Least Flycatcher	Total abundance	-0.23	0.122
	Relative abundance	-0.22	0.128
Least Sandpiper	Total abundance	0.22	0.140
	Relative abundance	0.22	0.140
Lesser Scaup	Total abundance	0.08	0.579
	Relative abundance	0.08	0.580
Lincoln's Sparrow	Total abundance	-0.14	0.335
	Relative abundance	-0.14	0.335
Lake and pond - primary habitat[2]	Total abundance	0.06	0.665
	Proportion (number of individuals/number of species)	0.04	0.792
	Relative abundance	0.11	0.476
	Richness	0.12	0.430
Grassland low disturbance indicators (Western Meadowlark, Northern Pintail, Baird's Sparrow)[3]	Total abundance	-0.02	0.877
	Relative abundance	-0.01	0.957
Parkland low disturbance indicators (Red-eyed Vireo, Black-capped Chickadee, Chipping Sparrow, White-throated Sparrow, Red-breasted Nuthatch) [3]	Total abundance	-0.43	0.002
	Proportion (number of individuals/number of species)	-0.44	0.002
	Relative abundance	-0.41	0.003
	Richness	-0.42	0.003
Bark gleaner - primary feeding habit, and Tree - primary nesting location[2]	Total abundance	-0.23	0.116
	Proportion (number of individuals/number of species)	-0.15	0.294
	Relative abundance	-0.21	0.152
	Richness	-0.25	0.089
Marbled Godwit	Total abundance	0.02	0.915

	Relative abundance	0.04	0.797
Mallard	Total abundance	0.23	0.116
	Relative abundance	0.24	0.099
Marsh - primary habitat[2]	Total abundance	0.07	0.644
	Proportion (number of individuals/number of species)	-0.03	0.822
	Relative abundance	0.22	0.142
	Richness	0.11	0.454
Merlin	Total abundance	-0.22	0.140
	Relative abundance	-0.22	0.140
Multiple broods - nesting habit[2]	Total abundance	-0.07	0.639
	Proportion (number of individuals/number of species)	-0.08	0.597
	Relative abundance	0.14	0.331
	Richness	-0.04	0.807
Mourning Dove	Total abundance	0.03	0.860
	Relative abundance	0.03	0.860
Marsh, lake/pond, Shoreline - primary habitat[2]	Total abundance	0.08	0.594
	Proportion (number of individuals/number of species)	-0.12	0.405
	Relative abundance	0.19	0.195
	Richness	0.13	0.384
Nelson's Sparrow	Total abundance	-0.18	0.208
	Relative abundance	-0.18	0.225
Northern Flicker	Total abundance	0.27	0.063
Northern Pintail	Total abundance	-0.11	0.459
	Relative abundance	-0.11	0.456
Northern Shoveler	Total abundance	-0.12	0.422
	Relative abundance	-0.10	0.512
Nest parasite - nesting habit[2]	Total abundance	-0.10	0.503
	Proportion (number of individuals/number of species)	-0.09	0.542
	Relative abundance	-0.09	0.557
	Richness	-0.07	0.625

Nuts - primary diet[2]	Total abundance	-0.08	0.596
	Proportion (number of individuals/number of species)	-0.08	0.591
	Relative abundance	0.00	0.989
	Richness	0.02	0.908
Obligate wetland species[2]	Total abundance	0.11	0.461
	Proportion (number of individuals/number of species)	-0.06	0.693
	Relative abundance	0.16	0.292
	Richness	0.12	0.410
Omnivore - diet classification[2]	Total abundance	-0.14	0.339
	Proportion (number of individuals/number of species)	-0.07	0.661
	Relative abundance	0.18	0.210
	Richness	-0.07	0.654
Open woodland - primary habitat[2]	Total abundance	-0.20	0.176
	Proportion (number of individuals/number of species)	-0.07	0.643
	Relative abundance	-0.11	0.462
	Richness	-0.30	0.041
Ovenbird	Total abundance	-0.24	0.105
	Relative abundance	-0.24	0.105
Pileated Woodpecker	Total abundance	-0.25	0.090
	Relative abundance	-0.25	0.090
Plants - primary diet[2]	Total abundance	0.15	0.294
	Proportion (number of individuals/number of species)	0.20	0.180
	Relative abundance	0.18	0.223
	Richness	0.12	0.435
Probes - primary feeding habit[2]	Total abundance	0.07	0.619
	Proportion (number of individuals/number of species)	0.02	0.873
	Relative abundance	0.11	0.452
	Richness	0.16	0.291
Ring-billed Gull	Total abundance	0.22	0.140
	Relative abundance	0.22	0.140

Red-breasted Nuthatch	Total abundance	-0.13	0.388
	Relative abundance	-0.12	0.426
Ruby-crowned Kinglet	Total abundance	-0.24	0.105
	Relative abundance	-0.24	0.105
Redhead	Total abundance	0.19	0.205
	Relative abundance	0.19	0.199
Reeds - primary nesting location[2]	Total abundance	0.10	0.503
	Proportion (number of individuals/number of species)	0.05	0.713
	Relative abundance	0.18	0.220
	Richness	0.19	0.204
Resident - migration habit[2]	Total abundance	0.03	0.821
	Proportion (number of individuals/number of species)	0.00	0.983
	Relative abundance	0.07	0.622
	Richness	0.02	0.901
Red-eyed Vireo	Total abundance	-0.18	0.219
	Relative abundance	-0.18	0.212
Total avian community species richness/site		-0.11	0.455
Ring-necked Duck	Total abundance	0.09	0.545
	Relative abundance	0.09	0.545
Ring-necked Pheasant	Total abundance	0.14	0.332
	Relative abundance	0.15	0.311
Red-tailed Hawk	Total abundance	-0.03	0.854
	Relative abundance	-0.02	0.886
Rusty Blackbird	Total abundance	-0.07	0.644
	Relative abundance	-0.07	0.644
Ruddy Duck	Total abundance	-0.12	0.412
	Relative abundance	-0.12	0.412
Ruffed Grouse	Total abundance	-0.11	0.462
	Relative abundance	-0.12	0.415
Red-winged Blackbird	Total abundance	0.07	0.628

	Relative abundance	0.16	0.272
High disturbance waterfowl indicators (Red-winged Blackbird, American Coot, Redhead)[3]	Total abundance	0.07	0.617
	Relative abundance	0.16	0.289
Savannah Sparrow	Total abundance	0.09	0.525
	Relative abundance	0.16	0.271
Scrub - primary nesting location[2]	Total abundance	-0.21	0.156
	Proportion (number of individuals/number of species)	-0.16	0.264
	Relative abundance	-0.15	0.296
	Richness	-0.26	0.070
Seeds - primary diet[2]	Total abundance	-0.07	0.617
	Proportion (number of individuals/number of species)	-0.19	0.195
	Relative abundance	0.04	0.809
	Richness	0.02	0.902
Shannon diversity index	Calculated using vegan R package (Okasanen et al., 2016)	-0.15	0.318
Stalking and probing - primary feeding habit[2]	Total abundance	0.07	0.619
	Proportion (number of individuals/number of species)	0.02	0.873
	Relative abundance	0.11	0.452
	Richness	0.16	0.291
Shrub - primary nesting location[2]	Total abundance	-0.27	0.066
	Proportion (number of individuals/number of species)	-0.16	0.280
	Relative abundance	-0.23	0.115
	Richness	-0.31	0.032
Shoreline - primary habitat[2]	Total abundance	0.05	0.748
	Proportion (number of individuals/number of species)	0.05	0.761
	Relative abundance	0.07	0.644
	Richness	0.08	0.568
Shrub and tree - primary nesting location[2]	Total abundance	-0.28	0.055
	Proportion (number of individuals/number of species)	-0.15	0.315
	Relative abundance	-0.26	0.077
	Richness	-0.31	0.029

Simpson diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.19	0.197
Small animals - primary diet[2]	Total abundance	-0.11	0.462
	Proportion (number of individuals/number of species)	-0.11	0.462
	Relative abundance	-0.11	0.470
	Richness	-0.10	0.495
Sora	Total abundance	-0.16	0.273
	Relative abundance	-0.16	0.269
Song Sparrow	Total abundance	-0.07	0.617
	Relative abundance	-0.03	0.831
Special concern - Federal or Alberta provincial listing as Species-at-Risk[2]	Total abundance	-0.08	0.595
	Proportion (number of individuals/number of species)	-0.09	0.565
	Relative abundance	-0.08	0.595
	Richness	-0.05	0.757
Sprague's Pipit	Total abundance	-0.16	0.268
	Relative abundance	-0.16	0.284
Surface diver - primary feeding habit[2]	Total abundance	0.07	0.651
	Proportion (number of individuals/number of species)	0.05	0.738
	Relative abundance	0.05	0.712
	Richness	0.06	0.694
Structures - primary nesting location[2]	Total abundance	0.10	0.494
	Proportion (number of individuals/number of species)	0.10	0.494
	Relative abundance	0.10	0.494
	Richness	0.10	0.515
Swamp Sparrow	Total abundance	-0.22	0.140
	Relative abundance	-0.22	0.140
Swainson's Thrush	Total abundance	-0.22	0.140
	Relative abundance	-0.22	0.140
Number of individuals/site		-0.21	0.161
Tree - primary nesting location[2]	Total abundance	-0.22	0.131
	Proportion (number of individuals/number of species)	-0.17	0.241

	Relative abundance	-0.20	0.171
	Richness	-0.24	0.105
Tree Swallow	Total abundance	0.06	0.683
	Relative abundance	0.07	0.642
Tropical migrant - migration habit[2]	Total abundance	-0.19	0.185
	Proportion (number of individuals/number of species)	-0.30	0.040
	Relative abundance	-0.20	0.163
	Richness	-0.10	0.491
Unbiased Simpson diversity index[4]	Calculated using vegan R package (Okasanen et al., 2016)	-0.14	0.326
Upland Sandpiper	Total abundance	0.00	0.983
	Relative abundance	0.00	0.990
Vesper Sparrow	Total abundance	0.45	0.001
	Relative abundance	0.45	0.001
Surface diver and dabbler - primary feeding habit[2]	Total abundance	0.08	0.610
	Proportion (number of individuals/number of species)	-0.01	0.924
	Relative abundance	0.14	0.347
	Richness	0.14	0.356
Reeds and floating - primary nesting location[2]	Total abundance	0.09	0.547
	Proportion (number of individuals/number of species)	0.08	0.597
	Relative abundance	0.16	0.286
	Richness	0.09	0.556
Waterfowl species[2]	Total abundance	0.09	0.549
	Proportion (number of individuals/number of species)	-0.01	0.963
	Relative abundance	0.14	0.359
	Richness	0.13	0.366
Western Meadowlark	Total abundance	0.03	0.860
	Relative abundance	0.07	0.629
Willet	Total abundance	0.07	0.633
	Relative abundance	0.09	0.549
Wilson's Phalarope	Total abundance	-0.05	0.756

	Relative abundance	-0.04	0.794
Wilson's Snipe	Total abundance	0.08	0.574
	Relative abundance	0.07	0.653
White-throated Sparrow	Total abundance	-0.44	0.002
	Relative abundance	-0.43	0.002
Yellow Warbler	Total abundance	-0.25	0.082
	Relative abundance	-0.24	0.102
Yellow-headed Blackbird	Total abundance	0.26	0.073
	Relative abundance	0.26	0.072

[1] For each metric, four variations were calculated. For metrics based on a single species or was composed of three or less grouped species, only total abundance and relative abundance were calculated. Total abundance was the sum of all individuals for that specific metric at each site. Relative abundance was the sum of the total number of individuals for the specific metric divided by all the individuals counted at the site. For the metrics that were based on a group of species, from trait characteristics or indicator species, the proportion and richness were calculated in addition to the total and relative abundance. For the proportion, this variation was calculated for each metric by summing all the number of individuals for the specified metric and dividing by the number of species for the specified metric. For the richness, this variation was calculated by summing the number of species for the specified metric.

[2]Trait-based metric based on species traits as outlined in Appendix 4.

[3]Species indicators grouped based on analyses by Polan (2016).

[4]Diversity indices were calculated based on referenced methods for each site visited.

Appendix 10. Pearson correlation coefficient matrix for redundancy analysis for Both Regions IBI. Methods for selection of metrics included in IBI explained in text. Metric variants depicted (TA = total abundance, RA = relative abundance, Sp = richness, PR = proportion). Species codes according to the American Ornithologists Union standards (American Ornithologists' Union, 1983).

	Bark Gleaner_Sp	CHSP_TA	Foliage Gleaner_RA	Forest and open woodland_Sp	Forest habitat_Sp	Fruit diet_RA	Hover and Glean_Sp	Parkland low disturbance indicators_PR	Open Woodland habitat_Sp	Shrub nester_Sp	Shrub and Tree nesters_Sp
Bark Gleaner_Sp											
CHSP_TA	0.89										
Foliage Gleaner_RA	0.88	0.85									
Forest and open woodland_Sp	0.86	0.84	0.95								
Forest habitat_Sp	0.93	0.90	0.93	0.92							
Fruit diet_RA	0.85	0.84	0.94	0.91	0.92						
Hover and Glean_Sp	0.88	0.81	0.92	0.90	0.89	0.89					
Parkland low disturbance indicators_PR	0.92	0.93	0.92	0.90	0.97	0.91	0.88				
Open Woodland habitat_Sp	0.84	0.82	0.94	0.99	0.87	0.89	0.90	0.87			
Shrub nester_Sp	0.78	0.78	0.92	0.88	0.83	0.85	0.85	0.82	0.88		
Shrub and Tree nesters_Sp	0.83	0.79	0.93	0.92	0.85	0.91	0.89	0.84	0.92	0.94	
Tropical migrant_PR	0.71	0.71	0.66	0.65	0.70	0.62	0.64	0.70	0.63	0.69	0.64
VESP_RA	0.70	0.72	0.63	0.62	0.66	0.64	0.67	0.68	0.63	0.55	0.63
WTSP_TA	0.86	0.93	0.89	0.86	0.93	0.86	0.85	0.94	0.84	0.80	0.80

	Tropical migrant_PR	VESP_RA	WTSP_TA
Bark Gleaner_Sp			
CHSP_TA			
Foliage Gleaner_RA			
Forest and open woodland_Sp			
Forest habitat_Sp			
Fruit diet_RA			
Hover and Glean_Sp			
Parkland low disturbance indicators_PR			
Open Woodland habitat_Sp			
Shrub nester_Sp			
Shrub and Tree nesters_Sp			
Tropical migrant_PR			
VESP_RA	0.57		
WTSP_TA	0.72	0.72	

Appendix 11. List of all study wetlands (n = 60) for Chapter 3, including year sampled, disturbance bin, size, non-natural land cover (%), and year of restoration for restored wetlands.

Site ID	Latitude	Longitude	Year Sampled	Disturbance bin	Size (m^2)	Non-natural Land cover (%)	Year Restored
10	52.51477	112.6479	2014	High	5499	79	NA
13	52.33939	112.2282	2015	Medium	1759	44	NA
18	52.58656	112.2081	2014	High	32810	82	NA
25	52.14848	111.8227	2014	High	5256	80	NA
30	52.38929	111.8738	2014	High	3233	96	NA
31	52.73904	113.3523	2015	Medium	3865	62	NA
32	52.59304	113.5987	2015	Low	3633	13	NA
35	53.07183	113.4282	2014	Medium	1998	45	NA
56	52.94941	112.6346	2015	High	1963	98	NA
67	52.46586	112.6971	2014	Low	1151	27	NA
89	52.34631	112.9285	2014	High	4043	94	NA
90	52.34705	112.8723	2014	High	2473	100	NA
182	52.73056	112.4106	2014	High	3443	99	NA
187	52.62288	112.6322	2014	High	6942	76	NA
190	53.09104	113.197	2014	High	4995	92	NA
194	52.21956	113.4428	2014	Medium	6653	36	NA
195	52.41014	113.044	2015	High	12973	8	NA
200	52.47809	112.6137	2014	Medium	10704	46	NA
301	51.87547	112.928	2015	High	1101	85	NA
317	53.18687	112.9959	2015	High	4445	57	NA
321	52.44961	111.7938	2015	High	1531	93	NA
333	53.26561	112.9496	2015	Low	11037	13	NA
344	52.11278	112.6716	2015	High	6290	81	NA
351	53.20609	113.2193	2015	High	3125	71	NA
365	52.92827	113.1265	2015	Medium	1041	26	NA
368	52.39511	111.1994	2015	Medium	625	13	NA
377	52.4848	113.0046	2015	High	358	71	NA
395	51.95862	112.7409	2015	High	2186	51	NA
396	53.07396	114.1662	2015	Low	567	29	NA

Site ID	Latitude	Longitude	Year Sampled	Disturbance bin	Size (m^2)	Non-natural Land cover (%)	Year Restored
398	52.99462	113.9092	2015	Medium	3476	65	NA
BATL	52.92772	114.1974	2014	Low	4114	5	NA
GAD	52.50925	113.2243	2014	Low	3614	19	NA
JJCOLL	52.55746	113.6309	2014	Low	16175	15	NA
MIQ	53.23397	112.8745	2014	Low	8559	3	NA
RUM	51.88395	112.6318	2015	Low	2303	0	NA
TOL	52.18618	113.0198	2014	Low	1690	8	NA
BARON01	52.44455	112.7391	2015	Restored	516	10	2012
BELTZ03	52.17432	113.5629	2015	Restored	763	51	2011
BERGQ07	53.17455	113.1446	2015	Restored	14036	68	2009
BUSEN01	53.15369	113.0611	2015	Restored	2402	76	2009
CAINE01	52.4808	112.6881	2015	Restored	297	7	2008
COLLI02	52.03028	113.2853	2015	Restored	7096	11	2013
FORBS10	53.08031	113.1942	2015	Restored	2601	78	2013
GILBE02	52.44124	112.72	2015	Restored	5480	6	2012
GRAND06	52.16313	112.6041	2015	Restored	7946	19	2008
GREEN03	52.5316	112.6689	2015	Restored	1237	20	2006
HEBER03	52.18951	112.5604	2015	Restored	3318	18	2012
HILLE03	52.47155	112.647	2015	Restored	1320	19	2008
HOLT04	52.8012	113.131	2015	Restored	10923	39	2004
HWY5302	52.58151	112.8063	2015	Restored	9840	42	2010
KERBE02	52.11289	112.9109	2015	Restored	3455	6	2007
KINVI03	51.99566	113.1183	2015	Restored	13932	13	2008
KINVI06	51.98447	113.1109	2015	Restored	1958	10	2008
LABYR02	53.10917	113.1604	2015	Restored	442	84	2010
LABYR56	53.12063	113.1794	2015	Restored	2772	81	2010
MIKA10	52.31523	112.9802	2015	Restored	1135	29	2009
OZMEN05	53.09171	112.8208	2015	Restored	3274	56	2011
PARLB01	52.42853	113.2345	2015	Restored	2725	6	2011
PEARL06	53.02945	112.4406	2015	Restored	3046	43	2011
RETTA09	53.17859	113.1595	2015	Restored	10849	68	2013

Appendix 12. Raw data for local and landscape level habitat characteristics and hydrology data for all sites samples for Chapter 3.

	HYDROLOGY					LOCAL HABITAT (within wetland boundary)							LANDSCAPE (within 500m buffer)						
Site ID	Maximum depth	Minimum depth	Amplitude	Amplitude /maximum depth	Date of wetland dry out	Broad-leaved emergents (%)	Narrow -leaved emergents (%)	Robust emergents (%)	Open water (%)	Woody vegetation (%)	Drawdown (%)	Ground cover (%)	Forest (%)	Wetland (%)	Water (%)	Urban (%)	Cultivated (%)	Pasture (%)	Grassland (%)
10	0.81	0.55	0.26	0.32	365	0	18.4	4.5	32.5	0	0	44.5	8.4	8.4	6.5	3.0	16.9	58.9	0.1
13	0.24	0.00	0.24	1.00	217	0	94.3	0	0	5.7	0	0	0.0	0.0	0.0	0.0	7.5	60.4	21.2
18	0.18	0.00	0.18	1.00	234	0	67	0	0	32.5	0.6	0	14.6	10.9	0.1	2.4	69.7	9.7	0.0
25	0.35	0.27	0.08	0.23	365	0	30.3	0	4.6	60.7	0	4.4	5.5	5.5	0.1	0.0	66.0	14.4	3.3
30	0.48	0.00	0.48	1.00	233	85.4	0	0	0	0	0	14.6	0.1	0.1	0.0	3.3	93.1	0.0	0.0
31	0.19	0.00	0.19	1.00	162	0	99.4	0.6	0	0	0	0	19.2	1.9	0.2	0.0	64.0	0.8	0.0
32	0.44	0.00	0.44	1.00	162	0	28.1	0	0	71.9	0	0	71.6	6.4	0.3	2.2	0.0	11.9	0.0
35	0.21	0.00	0.21	1.00	187	0	99.5	0	0	0	0.5	0	19.9	4.0	0.5	6.0	0.0	39.0	0.2
56	0.41	0.00	0.41	1.00	215	0	95.2	4.8	0	0	0	0	0.0	0.0	0.0	2.3	92.9	4.5	0.0
67	0.19	0.00	0.19	1.00	190	0	30.6	0	0	58.9	4.76	5.7	13.0	13.0	3.1	5.0	13.7	8.3	0.1
89	0.66	0.29	0.37	0.56	365	0	4.6	36.1	59.3	0	0	0	2.6	2.6	1.1	4.7	89.4	0.0	0.2
90	0.85	0.29	0.56	0.66	365	0	13.7	11.5	32.9	41.9	0	0	0.0	0.0	0.0	3.5	96.2	0.0	0.0
182	0.31	0.00	0.31	1.00	196	14	8.1	0	0	0	4	73.9	0.9	0.0	0.3	2.2	96.4	0.0	0.0
187	0.80	0.55	0.25	0.31	365	0	13.6	1	84	1.4	0	0	10.2	3.8	11.8	3.2	68.1	4.7	0.0
190	0.72	0.66	0.06	0.08	365	0	40.1	21.4	31.2	0	0	7.3	6.9	6.2	0.8	3.1	72.6	16.4	0.0
194	0.98	0.85	0.13	0.13	365	0	30.7	0.2	62.2	7	0	0	31.5	2.7	0.1	0.0	0.5	35.8	24.2
195	0.44	0.12	0.32	0.72	365	0	92.8	7.2	0	0	0	0	11.1	9.5	5.6	1.2	7.6	66.7	0.3
200	0.82	0.68	0.14	0.17	365	0	9.6	24.6	48.9	0	0	16.9	12.2	12.2	6.6	0.0	11.5	34.5	0.0
301	0.24	0.00	0.24	1.00	158	0	96	1	0	0	3	0	0.0	0.0	0.0	2.0	93.0	3.6	0.0
317	0.33	0.00	0.33	1.00	163	0	100	0	0	0	0	0	10.1	7.0	0.7	2.2	35.6	44.5	0.1
321	0.34	0.00	0.34	1.00	217	0	100	0	0	0	0	0	0.1	0.1	0.0	0.3	66.5	28.7	0.0

333	0.36	0.00	0.36	1.00	365	0	83.7	13	0	0	3.2	0	50.9	3.5	1.3	5.3	8.6	6.5	0.7
344	0.91	0.68	0.23	0.25	365	0	51.9	0	48.1	0	0	0	0.0	0.0	0.0	6.5	80.3	10.0	0.1
351	0.17	0.00	0.17	1.00	163	0	100	0	0	0	0	0	15.5	14.2	2.8	3.7	33.8	39.8	0.0
365	0.55	0.00	0.55	1.00	178	0	46.5	0	0	49.3	0	4.2	27.9	27.2	1.9	3.0	27.8	20.7	0.0
368	0.58	0.00	0.58	1.00	217	0	96.1	0	0	3.9	0	0	34.8	0.1	0.0	1.4	0.0	38.1	0.0
377	0.28	0.00	0.28	1.00	159	0	100	0	0	0	0	0	7.0	7.0	0.0	3.3	70.8	16.5	0.0
395	0.35	0.00	0.35	1.00	201	0	100	0	0	0	0	0	0.0	0.0	0.0	2.8	15.5	77.5	2.8
396	0.20	0.00	0.20	1.00	162	0	100	0	0	0	0	0	47.4	2.8	0.0	19.3	0.0	0.5	0.0
398	0.43	0.06	0.37	0.86	365	0	33.7	28.8	0	37.5	0	0	11.7	7.7	0.0	0.0	40.1	12.1	0.0
BATL	0.32	0.00	0.32	1.00	211	0	39.4	0	0.4	0	0	60.2	71.7	15.1	0.0	3.0	0.4	1.2	0.1
GAD	0.20	0.00	0.20	1.00	188	0	75.4	0	0	0	0	24.6	55.4	2.2	0.9	0.0	0.0	18.9	0.0
JJCOLL	0.90	0.35	0.55	0.61	365	0	43.9	0	12.45	43.6	0	0	72.1	1.7	0.0	2.8	0.6	11.4	1.0
MIQ	0.92	0.78	0.14	0.15	365	0	22.7	34.2	2.3	0	0	40.7	71.7	4.2	1.4	2.7	0.1	0.0	0.4
RUM	0.51	0.07	0.44	0.86	365	0	0	21.7	0	78.3	0	0	5.8	1.8	0.0	0.0	0.0	0.0	88.1
TOL	0.59	0.49	0.10	0.17	365	0	35.9	0	64	0	0	0	84.5	5.2	0.9	0.0	0.9	7.1	0.5
BARON01	0.16	0.00	0.16	1.00	160	0	49.4	0	0	0	0	50.6	34.6	32.1	8.8	3.9	0.6	37.8	0.0
BELTZ03	1.09	0.34	0.75	0.69	365	0	90.4	0	9.6	0	0	0	7.0	7.0	0.3	2.9	11.8	53.9	1.7
BERGQ07	0.76	0.54	0.22	0.29	365	0	50	0	50	0	0	0	3.4	2.5	0.1	2.8	22.2	68.8	0.0
BUSEN01	0.58	0.00	0.58	1.00	158	0	92.6	6.1	0	0	0	1.3	25.0	16.9	0.6	0.0	49.0	18.7	0.0
CAINE01	0.57	0.00	0.57	1.00	160	0	94.5	0	0	0	0	5.5	18.1	17.9	3.1	3.2	35.7	30.3	0.0
COLLI02	0.38	0.00	0.38	1.00	211	0	63.9	22.6	0	13.5	0	0	3.4	3.4	27.2	4.3	17.4	30.1	1.5
FORBS10	0.41	0.00	0.41	1.00	178	0	30.8	69.2	0	0	0	0	0.9	0.0	0.8	4.2	76.3	15.7	0.0
GILBE02	0.85	0.61	0.24	0.29	365	0	52	21.9	13.8	0	0	11.8	26.0	26.0	5.5	1.6	0.2	52.7	0.0
GRAND06	0.76	0.67	0.09	0.11	365	0	73.3	0	15.2	11.5	0	0	18.3	18.3	3.6	3.1	0.0	43.9	16.4
GREEN03	0.45	0.21	0.24	0.53	365	0	39.8	0	23.5	0	0	36.7	22.1	22.1	8.5	0.0	11.1	30.8	0.4
HEBER03	0.74	0.29	0.45	0.61	365	0	87.9	0	0	5.3	6.8	0	25.2	25.2	0.0	0.0	5.2	24.8	35.8
HILLE03	0.94	0.73	0.20	0.22	365	0	15.2	0	83.8	0	0	0.9	15.5	15.5	4.3	0.0	15.3	57.6	0.0
HOLT04	0.50	0.23	0.27	0.54	365	0	97.5	2.5	0	0	0	0	36.7	6.5	6.8	1.7	23.7	20.2	0.0
HWY5302	1.02	0.81	0.22	0.21	365	0	30.3	3.5	63.9	2	0.3	0	29.6	12.5	2.6	4.7	11.8	49.0	0.0

KERBE02	0.69	0.50	0.19	0.28	365	0	54.4	0	45.6	0	0	0	10.6	8.2	4.6	4.6	15.1	22.2	4.6
KINVI03	1.02	0.87	0.15	0.15	365	0	19.9	0	80.1	0	0	0	10.2	10.2	12.1	4.7	29.7	10.1	23.4
KINVI06	0.60	0.42	0.18	0.30	365	0	4.5	0	0	95.5	0	0	11.7	11.7	7.4	0.0	44.4	16.6	5.1
LABYR02	0.05	0.00	0.05	1.00	135	0	100	0	0	0	0	0	2.7	2.7	1.5	1.9	43.8	48.4	0.0
LABYR56	0.48	0.00	0.48	1.00	178	0	36.2	54.1	0	0	9.7	0	2.8	2.8	2.1	4.0	13.2	77.6	0.0
MIKA10	0.65	0.19	0.47	0.72	365	0	46.2	0	20.1	0	0	33.7	10.3	4.2	13.6	6.5	13.9	43.5	1.0
OZMEN05	0.72	0.00	0.72	1.00	215	0	52.5	24.3	0	0	0	23.2	5.9	0.8	3.8	0.0	74.3	13.0	0.0
PARLB01	0.86	0.36	0.51	0.59	365	0	7.4	0	23.3	68.4	0	0.9	48.3	48.3	1.5	3.4	5.5	20.3	0.6
PEARL06	0.36	0.00	0.36	1.00	177	0	100	0	0	0	0	0	0.6	0.6	4.9	2.9	30.0	61.0	0.0
RETTA09	0.25	0.00	0.25	1.00	178	0	100	0	0	0	0	0	3.9	2.2	6.5	0.0	66.3	18.9	0.0

Appendix 13. Subset of all avian species observed that were designated as either an obligate wetland or facultative wetland species, which were used in analyses considering only wetland-dependant species in Chapter 3. Wetland dependency based on Brooks and Croonquist (1990), Ehrilich et al. (1988), and Smith and Chow-Fraser (2010).

Common Name	Scientific Name	Wetland Obligate	Facultative Wetland	Upland
Alder Flycatcher	*Empidonax alnorum*		x	
American Avocet	*Recurvirostra americana*	x		
American Bittern	*Botaurus lentiginosus*	x		
American Coot	*Fulica americana*	x		
American Crow	*Corvus brachyrhynchos*			x
American Goldfinch	*Spinus tristis*			x
American Redstart	*Setophaga ruticilla*			x
American Robin	*Turdus migratorius*			x
American Wigeon	*Anas americana*	x		
Baltimore Oriole	*Icterus galbula*			x
Barn Swallow	*Hirundo rustica*			x
Black-billed Magpie	*Pica hudsonia*			x
Black-capped Chickadee	*Poecile atricapillus*			x
Brown-headed Cowbird	*Molothrus ater*			x
Blue Jay	*Cyanocitta cristata*			x
Black Tern	*Chlidonias niger*	x		
Brewer's Blackbird	*Euphagus cyanocephalus*		x	
Brown Thrasher	*Toxostoma rufum*			x
Bufflehead	*Bucephala albeola*	x		
Blue-winged Teal	*Anas discors*	x		
Canada Goose	*Branta canadensis*	x		
Canvasback	*Aythya valisineria*	x		
Clay-colored Sparrow	*Spizella pallida*			x
Cedar Waxwing	*Bombycilla cedrorum*			x
Chipping Sparrow	*Spizella passerina*			x
Cinnamon Teal	*Anas cyanoptera*	x		
Common Loon	*Gavia immer*	x		
Common Raven	*Corvus corax*			x
Common Yellowthroat	*Geothlypis trichas*			x

Common Name	Scientific Name	Wetland Obligate	Facultative Wetland	Upland
Downy Woodpecker	*Picoides pubescens*			x
Eared Grebe	*Podiceps nigricollis*	x		
Eastern Kingbird	*Tyrannus tyrannus*			x
Eastern Pheobe	*Sayornis phoebe*			x
European Starling	*Sturnus vulgaris*			x
Gadwall	*Anas strepera*	x		
Great Blue Heron	*Ardea herodias*	x		
Gray Catbird	*Dumetella carolinensis*			x
Grasshopper Sparrow	*Ammodramus savannarum*			x
Green-winged Teal	*Anas crecca*	x		
Hairy Woodpecker	*Picoides villosus*			x
Horned grebe	*Podiceps auritus*	x		
Horned Lark	*Eremophila alpestris*			x
House Sparrow	*Passer domesticus*			x
House Wren	*Troglodytes aedon*			x
Le Conte's Sparrow	*Ammodramus leconteii*		x	
Least Flycatcher	*Empidonax minimus*			x
Lesser Scaup	*Aythya affinis*	x		
Lesser Yellowlegs	*Tringa flavipes*	x		
Lincoln's Sparrow	*Melospiza lincolnii*		x	
Marbled Godwit	*Limosa fedoa*		x	
Mallard	*Anas platyrhynchos*	x		
Merlin	*Falco columbarius*			x
Mourning Dove	*Zenaida macroura*			x
Nelson's Sparrow	*Ammodramus nelsoni*	x		
Northern Flicker	*Colaptes auratus*			x
Northern Harrier	*Circus cyaneus*			x
Northern Pintail	*Anas acuta*	x		
Northern Shoveler	*Anas clypeata*	x		
Ovenbird	*Seiurus aurocapilla*			x
Pileated Woodpecker	*Dryocopus pileatus*			x
Ring-billed Gull	*Larus delawarensis*	x		
Red-breasted Nuthatch	*Sitta canadensis*			x
Ruby-crowned Kinglet	*Regulus calendula*			x
Redhead	*Aythya americana*	x		
Red-eyed Vireo	*Vireo olivaceus*			x
Ring-necked Duck	*Aythya collaris*	x		
Red-tailed Hawk	*Buteo jamaicensis*			x
Ruddy Duck	*Oxyura jamaicensis*		x	

Common Name	Scientific Name	Wetland Obligate	Facultative Wetland	Upland
Ruffed Grouse	*Bonasa umbellus*			x
Red-winged Blackbird	*Agelaius phoeniceus*	x		
Savannah Sparrow	*Passerculus sandwichensis*			x
Sora	*Porzana carolina*	x		
Song Sparrow	*Melospiza melodia*			x
Sprague's Pipit	*Anthus spragueii*			x
Swamp Sparrow	*Melospiza georgiana*	x		
Swainson's Hawk	*Buteo swainsoni*			x
Tennessee Warbler	*Oreothlypis peregrina*			x
Tree Swallow	*Tachycineta bicolor*			x
Vesper Sparrow	*Pooecetes gramineus*			x
Western Meadowlark	*Sturnella neglecta*			x
Willet	*Tringa semipalmata*	x		
Wilson's Phalarope	*Phalaropus tricolor*	x		
Wilson's Snipe	*Gallinago delicata*	x		
White-throated Sparrow	*Zonotrichia albicollis*			x
Yellow Warbler	*Setophaga petechia*			x
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	x		