# Restoring hydro-impacted wetlands for secretive marsh birds

**by**

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## Abstract

Secretive marsh birds can be difficult to detect and are dependent on wetlands, leaving them vulnerable to wetland loss or alteration. This study examines the influence of management-altered hydrological regimes on five secretive marsh bird species in the West Kootenay and Columbia Wetlands in British Columbia, Canada. Focal species occupied wetlands with less frequently altered hydrological regimes more often and in greater numbers. Occupancy models suggested that woody vegetation, tall vegetation, and open water are important drivers of occupancy for these species. Wetlands most frequently experiencing heavily altered hydrological regimes had more open water and less tall vegetation, both of which were negatively associated with wetland occupancy. Water management operations may be promoting altered vegetation communities within these wetlands, in turn promoting lower occupancy of secretive marsh bird species. Restoration recommendations include: prioritizing lower elevation wetlands, limiting woody vegetation encroachment, and experimentally restoring the hydrological regime of affected wetlands.

**Keywords**: secretive marsh bird; Kootenays; British Columbia; hydro; water management; wetlands

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## 1.1. Introduction

Globally, more than half of the world's major river systems are affected by at least one large dam (Nilsson et al. 2005, Lehner et al. 2011, Grill et al. 2015), collectively containing as much as 93% of the world's river volume (Grill et al. 2015). Growing demand for energy, flood control, and water security have spurred development of water management projects and put increasing anthropogenic pressure on river and riparian ecosystems. These projects often evoke radical changes in the surrounding region, entire ecosystems can be severely impacted by shifts in their natural flow regimes and functionality can be altered or lost entirely (Utzig and Schmidt 2011). Wetlands are often among those habitats most affected by water management projects. Wetland loss or alteration can in large part be attributed to a range of anthropogenic causes, including the creation of dams, reservoirs, and other water management projects. Declining wetlands have been a widespread concern for decades; historical reports indicate that since 1700 AD 54-57% of global natural wetland area has been lost, though this estimate could be as high as 87% (Davidson 2014). Alterations to habitat composition, connectivity, and functionality resulting from water management projects can have severe repercussions for the species which depend on them. Waterbirds, waders, songbirds, aerial insectivores, and amphibians are among the vertebrate groups experiencing the greatest impacts from water management projects (Utzig and Schmidt 2011). While research and management initiatives focused on the challenges facing wildlife in regulated-watersheds are on-going, questions remain and many species are showing concerning declines.

Marsh birds are among those groups experiencing the most severe repercussions of water management projects (Utzig and Schmidt 2011). They are wetland and riparian specialists and rely on wetlands for critical stages of their life history, making them especially vulnerable to wetland degradation and loss. The timing, duration, and degree of the inundation can affect the severity and extent to which marsh birds and their habitat are affected (Ellis et al. 2009, Kellner and van Oort 2011). Marsh birds may be affected by lost reproductive opportunities (Ellis et al. 2009, Kellner and van Oort 2011, van Oort et al. 2015), reduced fledgling survival or local recruitment (Hepp et al. 2018), altered or lost vegetation communities (Nilsson et al. 1997, Ellis et al. 2009), and other effects of inundation (Reitan and Thingstad 1999). Inundation may prompt a reduction in nesting attempts (southwestern willow flycatchers, *Empidonax traillii extimus*, Ellis et al. 2009) or flood existing nest sites (common loons, *Gavia immer*, Kellner and van Oort 2011). Emergent vegetation species are well-adapted to wetland environments and have evolved life history strategies which can be dependent on seasonal flooding (Blom and Voesenek 1996), however, if inundation is too frequent or extreme it can limit plant survival and establishment (Blom and Voesenek 1996, Campbell et al. 2016). Vegetation community assemblage is an important determinant of marsh bird presence (Murkin et al. 1982, Lor and Malecki 2006, Conway and Sulzman 2007, Baschuk et al. 2012, Nielson 2016) and proportions of vegetative to open water cover is often important as well (Kaminski and Prince 1981, Murkin et al. 1982, Lor and Malecki 2006). This can be problematic if altered hydrological regimes skew the ratio in an unfavourable direction. Altered or lost vegetation communities can ultimately result in the environment lacking in the components necessary for marsh birds to survive and thrive.

In a broader context, 44% of North American bird species had experienced population declines between 1970 and 2010 (NABCIC 2012). Across Canada aerial insectivores, shorebirds, nonwaterfowl-waterbirds (e.g., grebes and loons), and forest birds have experienced declines since 1970, which in some instances are substantial (NABCIC 2012). These trends raise significant concerns given the increasing stress being placed on critical ecosystems avian groups depend on, including wetlands and marshes. Across North America many marsh bird species are declining (Sauer et al. 2017), declines closely tied to disappearing wetlands which they depend on (Conway et al. 1994). Marsh birds include members of the rail (Rallidae), heron (Ardeidae), and grebe (Podicipedidae) families, though dependence on marsh habitat may differ across individual species. While some members of these families are frequently observed, some are challenging to study due to their more inconspicuous nature. These are termed secretive marsh birds and they can be difficult to detect as they may vocalize little or very quietly, have cryptic colouration, and/or may occupy densely vegetated areas (Conway 2011). Given their dependence on wetland habitat and their elevated risk of suffering from water management-related impacts, secretive marsh birds can serve as important indicators of wetland quality (Conway 2011, Tozer 2013). Due to the secretive nature their populations, however, the effects of wetland loss, degradation, or alteration on secretive marsh bird populations are poorly understood. Without a clear understanding of these populations and their requirements, restoration and management efforts aimed at offsetting or mitigating the effects of development can lack informed targets and goals.

The Columbia River drainage basin, or Columbia Basin, is the drainage basin of the Columbia River encompassing a portion of southeastern British Columbia and extending into the United States. The Columbia River Treaty (1964) is a transboundary water management agreement between Canada and the United States, ratified in 1964, with the goal of coordinating flood control and optimizing hydroelectric energy production between both countries. This treaty prompted the creation of several large-scale dam and reservoir projects on the Columbia River. Development has continued since that time and today the Columbia River and its tributaries have approximately 500 dams, making it one of the largest hydroelectric systems in the world (Toller and Nemetz 1997). In addition to sociocultural impacts, intensive hydroelectric development within the Columbia Basin has altered or degraded extensive areas of aquatic and terrestrial ecosystems. For example, the Columbia Basin has lost 1,604 linear kilometres of riverine habitat as a result of BC Hydro operations (Thorley 2008). The creation of reservoirs has increased the area of larger lakes (Thorley 2008), but while lakes and reservoirs may appear superficially similar their associated ecosystem types, composition, and values can diverge considerably (Drakou et al. 2008). The operational footprint of BC Hydro dams alone has resulted in the loss of 68,474 hectares of terrestrial ecosystems in the Columbia Basin, including 7,705 hectares of wetlands (Utzig and Schmidt 2011). This represents an overall loss of 26% of wetland area across dam footprints (Utzig and Schmidt 2011), but some dam footprints have lost 60-80% of the local wetland area.

The Columbia Basin is within the Pacific Flyway, a major north-south flight path from the Arctic to South America used by migratory birds. Electricity demand within BC is only expected to grow, and while hydroelectricity may offer improvements over carbon-heavy electricity production there is still a critical need to address the effects these projects have on vulnerable species and ecosystems. In this study, I considered how frequently wetlands would experience an altered hydrological regime due to water management project operations. I examined how this might influence the densities of five secretive marsh bird species found in the Columbia Basin: American bittern (*Botaurus lentiginosus*), American coot (*Fulica americana*), pied-billed grebe (*Podilymbus podiceps*), sora (*Porzana carolina*), and Virginia rail (*Rallus limicola*). These species were surveyed in two regions within British Columbia, Canada: the West Kootenay and the Columbia Wetlands. I then examined aspects of the wetland ecosystem by the frequency of water management impacts, focusing on the structural composition of major habitat types and vegetation communities. Finally, I used occupancy models to assess the important driving forces behind marsh bird occupancy. I used the results of this study to inform recommendations for supporting these bird populations and restoring their wetland environment.

## 1.2. Methods

We surveyed secretive marsh birds in the Southern Interior Mountains (SIM) ecoprovince of BC, a region which encompasses the Columbia Mountains, Southern Rocky Mountain Trench, and the Continental Ranges of the Rocky Mountains (Demarchi 2011). Observers collected count data between 2013 and 2018 using the *Standardized North American Marsh Bird Monitoring Protocol* as outlined by Conway (2011) and in accordance with the *Prairie and Parkland Marsh Monitoring Program* (BSC 2010). In the West Kootenay, we collected data from 2013-2015 and 2017-2018. In the Columbia Wetlands, we collected data between 2016 and 2018. American bittern, American coot, pied-billed grebe, sora, and Virginia rail were the focal species of these surveys. We collected vegetation and habitat variables at each survey station annually to complement the count data.

### Study Area and Species

I examined survey data focused on secretive marsh birds in the West Kootenay and Columbia Wetlands of British Columbia (Figure 1), evaluating how the frequency of water management operations related to wetland structure, marsh bird density, and wetland occupancy.

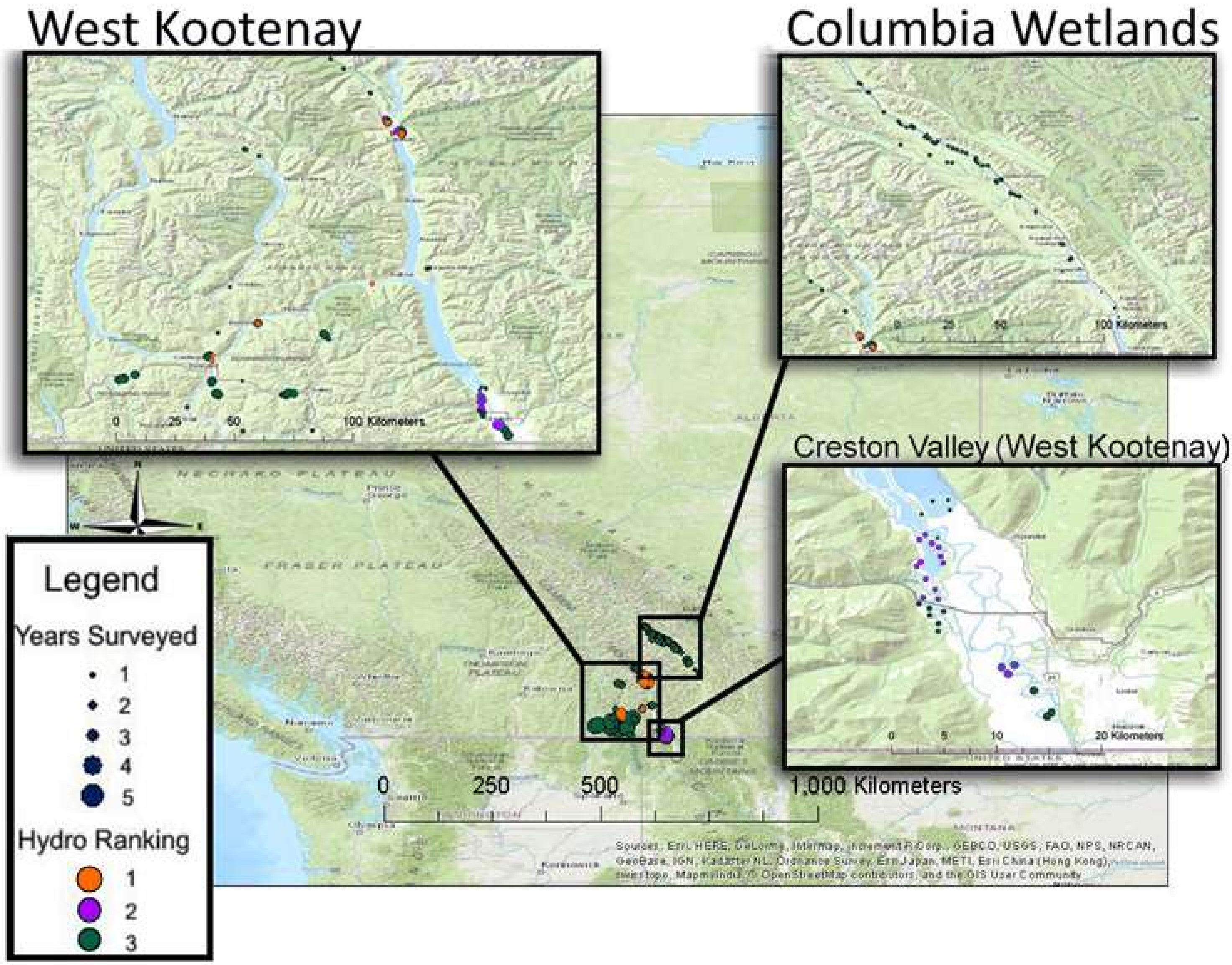



*Figure 1. Map of southern British Columbia with insets of study regions. Relative size of points indicates the number of years the station has been surveyed ("Years Surveyed"), colour indicates the frequency of which a station is influenced by hydroelectric or water management projects ("Hydro Ranking"). Hydro rankings are categorized as follows: 1 = station is always impacted, 2 = station is occasionally impacted, 3 = station is never impacted. Note: Creston Valley stations are included within the West Kootenay study area. Permanent station attributes are summarized in Appendix A.*

Surveys were focused on five marsh bird species: American bittern, American coot, pied-billed grebe, sora, and Virginia rail. They are defined by Conway (2011) as secretive marsh birds, though they vary in their degree of conspicuousness, and exhibit some variation in nesting preferences, diet, and foraging strategies (Table 1).

*Table 1. Summary of key characteristics of the five focal species of this study. These species are classified as secretive marsh birds of note by Conway (2011). These characteristics were used in part to guide modelling analyses.*

| Name | Diet Composition | Foraging Style | Nesting Preferences |
|---|---|---|---|
| American bittern (*Botaurus lentiginosus*)[1,2,10] | Fish, aquatic prey | Stalking | Among dense vegetation built with cattails (*Typha* spp.), rushes (*Scirpus/Juncus* spp.), and/or bulrushes (*Sparganium* spp.) |
| American coot (*Fulica americana*)[3,4,10] | Vegetation, invertebrates, aquatic prey | Dabbling, diving | Floating nests with dense vegetation such as cattails, rushes, and bulrushes |
| Pied-billed grebe (*Podilymbus podiceps*) [2,5,6,10] | Insects, fish, aquatic prey | Diving | Floating nests of bulrushes, rushes, cattails, or other vegetation |
| Sora (*Porzana carolina*)[2,7,8,10] | Seeds, insects, aquatic invertebrates | Surface feeder | Among dense vegetation, with cattails and rushes |
| Virginia rail (*Rallus limicola*) [2,8,9,10] | Insects, aquatic invertebrates, seeds | Probing | Among dense vegetation, with cattails and rushes, prefers a canopy over the nest (of grasses or other) |

[1] Bent 1926, pp 72-84
[2] Lor and Malecki 2006
[3] Bent 1926, pp 358-371
[4] Gorenzel et al. 1982
[5] Bent 1919, pp 39-47
[6] Forbes et al. 1989
[7] Bent 1926, pp 303-316
[8] Horak 1970
[9] Bent 1926, pp 292-30
[10] Cornell Lab of Ornithology n.d.

Across North America many secretive marsh bird species are thought to be declining (Sauer et al. 2017). These five species have all been identified as potentially suffering “very high” or “high” habitat-related impacts from hydro operations in the Columbia Basin, based on species-habitat associations and the risk of losing those habitats as a result of hydro operations (Manley and Krebs 2011). Additionally, the Great Lakes Marsh Monitoring Program have found population declines in all five of these species within the Great Lakes area of Ontario (Tozer 2013). Of these five species, only the American coot has been federally assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and was deemed “Not at Risk” in April 1991 (COSEWIC 2001). Within British Columbia, American coot (BC Conservation Data Centre [BC CDC] 1994a), pied-billed grebe (BC CDC 1995a), sora (BC CDC 1996), and Virginia rail (BC CDC 1995b) are considered “Secure” (rank S5) or “Apparently secure with some cause for concern” (rank S4) and all are currently Yellow-listed. The breeding population of American bittern in British Columbia is currently assessed as “Vulnerable” (rank S3B) and bittern are currently Blue-listed, indicating they are of concern provincially (BC CDC 1994b).

### *West Kootenay*

The West Kootenay study region is within the three southern sections of the Columbia mountain range, between the Monashee and Purcell ranges specifically (Figure 1). The Kootenay and Columbia rivers both flow through this region and several large lakes are present, including: Kootenay, Duncan, and Upper Arrow Lakes. The complex geography of the region, featuring multiple mountain ranges, lakes, and rivers, lends itself to an overall wetter climate compared to the Columbia Wetlands. In my study area, the lower elevations are generally within the Interior Cedar-Hemlock (ICH) Biogeoclimatic (BEC) zone (Ketcheson et al.1991) and higher elevations are within the Engelmann Spruce-Subalpine Fir (ESSF) BEC zone (Coupé et al. 1991). The West Kootenay have been extensively developed by hydroelectric and water management projects, including facilities operated by BC Hydro, FortisBC, Nelson Hydro, and Columbia Power. In the southern end of the West Kootenay, the Creston Valley Wildlife Management Area (WMA) is a 7,000-ha area of crown land protected by the *Creston Valley Wildlife Act* (RSBC 1996 c. 84). The WMA is within the Kootenay River system and is being managed to support wildlife and waterfowl habitat (CVWMA n.d.). Outside this WMA, wetlands to the south of Creston are managed by the Yaqan Nukiy (Lower Kootenay Band). These wetlands are within Ktunaxa Nation Traditional Territory and were originally established by Ducks Unlimited. Both the WMA and Lower Kootenay Band wetlands have their water levels managed by a series of dykes, control structures, and pumps.

### *Columbia Wetlands*

The Columbia Wetlands are located within the Rocky Mountain Trench between the Rocky and Purcell mountain ranges. These wetlands are the source for the north-flowing Columbia River, occupying the floodplain from Canal Flats and flowing approximately 180 km north to the Mica Dam Reservoir (Pedology et al. 1983, pp 11). This topographical positioning impacts the climate of the valley, buffering air currents moving through the region. The northern portion of the wetlands, including the town of Golden, are within the Montane Spruce (MS) BEC zone (Hope et al. 1991b). Moving south, the wetlands transition into the ICH BEC zone with a large southern section in the Interior Douglas Fir (IDF) zone (Hope et al. 1991a). This section of the Columbia River has a very gentle gradient, allowing the diversity of available habitats to flourish and resulting in channels, lakes, ephemeral and permanent marshes, wet meadows, and forested areas intermingling throughout the wetlands. The Columbia Wetlands WMA, East Side Columbia Lake WMA, multiple units of the Columbia National Wildlife Area (NWA), and other conservation land acquisitions are within the Columbia Wetlands. The Columbia Wetlands represent a relatively unimpacted region of high-quality habitat for wildlife. Areas like the Columbia Wetlands provide important stop-over points for birds during their migration in addition to nesting, feeding, and resting sites during other points of the year.

## Data Collection

### *Bird Surveys*

I collated data from marsh bird surveys conducted at 34-60 stations in the West Kootenay and 35-65 stations in the Columbia Wetlands (Figure 1, Appendix A). Survey data was collected by M-A. Beaucher and J. Arndt in the West Kootenay from 2013-2018, excluding 2016, and by R. Darvill and V. Shaw in the Columbia Wetlands from 2016-2018. The first surveys began 30 minutes prior to sunrise (earliest occurring at 0420) and were completed by 1000 in almost all instances, the latest survey occurring at 1140 in 2014. Each station was surveyed 1-3 times between1 May and 6 July each year, based on timing windows outlined by Conway (2011) and local conditions. Reserve lands were surveyed with permission of the Yaqan Nukiy (Lower Kootenay Band) in the West Kootenay and Akisqnuk First Nation in the Columbia Wetlands.

Bird surveys followed the *Prairie and Parkland Marsh Monitoring Program* (hereafter, *Marsh Monitoring Program*) developed by Bird Studies Canada ([BSC] 2010) and the *Standardized North American Marsh Bird Monitoring Protocol* by Conway (2011). These protocols use broadcast-callback survey techniques to elicit responses from target species. Under these protocols, permanent point survey stations were set up in each study region and marked with GPS. Even if a station no longer contained suitable habitat in later years, it was still surveyed. Stations were spaced a minimum of 400 m apart and the direction speakers faced was clearly indicated on data sheets. Surveys conducted using slightly different protocols, such as an altered broadcast sequence in 2012 at the Creston Valley stations and 2014 at the Revelstoke Reach stations or evening surveys as opposed to morning in 2010 and 2011 at the Creston Valley stations, were excluded from these analyses. The broadcast-callback method is especially effective for detecting rails compared to exclusively passive surveys (Conway and Gibbs 2005). Gibbs and Melvin (1993) demonstrated that this can be an effective technique for detecting secretive marsh birds. To detect secretive species with 90% certainty, two visits are necessary when surveying for sora, Virginia rail, and pied-billed grebe and three visits for American bittern (Gibbs and Melvin 1993). Based on this reasoning, I excluded stations which were only surveyed once during a season from analyses.

Stations were surveyed using a 15-minute broadcast sequence (BSC 2010). The broadcast sequence was as follows: 5-minute passive (silent) segment, 1-minute species-specific broadcast segments for each focal species (i.e., five minutes total in this study), and a final 5-minute passive segment. Each 1-minute species-specific broadcast consisted of 30 seconds of recorded calls followed by 30 seconds of silence. Identical broadcast sequences were used at all survey stations in all years. All surveys were single-observer with no additional participation from other observers present. Surveying began with the start of the first passive segment and observers recorded instances of aural and/or visual detections of focal species. In addition to recording the presence of a bird, observers provide an estimate of the distance between the observer and the birds location when first detected (BSC 2010). These were recorded as binned distances, indicating whether the bird was 0-50 metres, 50-100 metres, or more than 100 metres from the observer. Detections which occurred prior to or after the survey were not included in analyses. If a bird was suspected to have been detected at a previous station, the bird was recorded with notes indicating that it was previously detected and it was only included in the final count for station where it was first detected. Surveys were only conducted if conditions were favourable and the *Marsh Monitoring Program* outlines specific acceptable thresholds for precipitation, wind, and background noise (BSC 2010). In summary, for each survey the species detected, number of individuals, and the associated distance from observer for each individual was recorded (Appendix B).

### *Wetland Characteristics*

We collected vegetative cover and environmental data annually at each station according to the *Marsh Monitoring Program* survey protocol (BSC 2010, Appendix B). Vegetation surveys were conducted from late June to early July, when most plant species were readily identifiable and bird surveys were complete. The *Marsh Monitoring Program* partitions wetland characteristics into three main sections: A) relative percentage cover of 'Major Wetland Habitats', B) percentage of 'open water' covered by floating vegetation partitioned by species, and C) percentage of 'herbaceous emergent vegetation' cover partitioned by species (Appendix C).

I used these surveys to compile a list of wetland characteristics to model marsh bird detection and occupancy (Table 2). Stations span both high and low elevations (Appendix A) which can have a variety of ecological implications which are important to consider, including variations in local climate and vegetation assemblages. Negative associations with woody vegetation, trees and shrubs, have been documented for some marsh bird species (Naugle et al. 1999, Darrah and Krementz 2009 and 2010, Bolenbaugh et al. 2011, Nielson 2016). This may be due to increased presence of avian and mammalian predators with the increasing perching sites and foraging areas provided by woody vegetation (Naugle et al. 1999, Darrah and Krementz 2010). Emergent vegetation cover and/or species composition is frequently correlated with marsh bird presence (Forbes et al. 1989, Fairbairn and Dinsmore 2001, Lor and Malecki 2006, Darrah and Krementz 2009, Bolenbaugh et al. 2011, Baschuk et al. 2012). Emergent vegetation also has strong ecological relevance as a source of food, cover, and/or nesting material (Table 1), and based on results can provide opportunities for informing restoration initiatives. For the purposes of this study, two variables were considered separately for emergent vegetation: 1) total percent cover of emergent vegetation ("Section A", Appendix B) and 2) percent cover of tall emergent vegetation only (cattails and rushes). Open water is an important variable to consider, especially for American coot (Gorenzel et al. 1982) and pied-billed grebe (Forbes et al. 1989), which both build floating nests and will dive in search of submerged sources of food (Table 1). Seasonal timing is frequently considered in the literature, though its importance and effects vary between species (Harms and Dinmore 2014, Tozer et al. 2016). Day since 1 May was used to examine the effect of seasonal timing on detection.

*Table 2. Detailed descriptions of wetland characteristics collected at survey stations in the West Kootenay and Columbia Wetlands (see Appendices A-C) that were used in occupancy modelling analyses.*

| Variable | Description |
|---|---|
| Region | Study region, treated as a factor with two levels where West Kootenay = 1 and Columbia Wetlands = 0 |
| Year | Year in the study, treated as a factor with five levels in the West Kootenay and three levels in the Columbia Wetlands |
| Day | Day on which a survey was conducted, measured as days since May 1 (i.e., 1 June would be “32”) |
| Hydro Ranking | Qualitative ranking system for survey stations, treated as a factor with three levels (1-3), stations are ranked according to their position in the impacted watershed and how frequently their hydrological regime is altered by water management operations |
| Water | Relative percent cover of open water within 100 metres of a station |
| Elevation | Elevation of station (metres above sea level, m) |
| Woody | Relative percent cover of shrubs and trees within 100 metres of a station |
| Emergent | Relative percent cover of all emergent/submergent vegetation within 100 metres of a station |
| Tall | Relative percent cover of tall emergent vegetation within the “emergent/submergent vegetation” category (Appendix B), determined by combining percent cover of cattails and rushes |

### *Water Management Impacts*

I assigned stations within the West Kootenay a hydro ranking according to how frequently hydroelectric project or water management-related activities affect their natural hydrological regime. These rankings are as follows: 1 = station is always impacted, 2 = station is occasionally impacted, and 3 = station is never impacted. Stations with a hydro ranking of 2 are only affected during years where water levels are elevated to the extent that the wetland connects to an affected waterway (J. Arndt and M. Drever 2018, personal communication). This qualitative index of disturbance measures how connected a station is to a hydro- or management-regulated watershed and how frequently they would be affected by management actions. Water management-related impacts may include altered length, timing, and severity of inundation from natural conditions, among others. These impacts are not necessarily shared across affected stations or between years at the same station. However, this ranking system allows us to gauge how increasing divergence from the natural hydrological regime of the region influences marsh birds and the characteristics of wetlands they inhabit. All stations within the Columbia Wetlands region are not affected by hydro development or water management projects, therefore are given a hydro ranking of 3 indicating they are never impacted.

## Analyses

### *Density Estimates*

I estimated population density using Distance 7.2 Windows package by Thomas et al. (2010). Observations were defined as binned distances as they were initially recorded. I analyzed species-specific input by year for both regions and by hydro ranking within the West Kootenay. For each year I estimated the densities of all five species in the Columbia Wetlands and four species in the West Kootenay. The American bittern was not observed in the West Kootenay during this study, therefore its density could not be estimated. Following the approach recommended by Buckland et al. (2001), I selected a key function followed by a series expansion. Models using the key function “Half-normal” and series expansion “cosine” outperformed those using “Hazard-rate” or “Uniform” functions in almost all cases. To assess relative model fit, Buckland et al. (2001) recommend maximum likelihood methods using Akaike Information Criterion (AIC) to estimate the quality of each model relative to the others. The model with the lowest AIC was selected. Year-by-year results were then averaged to provide an overall estimate for each species by region and hydro ranking. This approach facilitates comparisons in bird densities by both region and hydro ranking while accounting for year-to-year variability.

### *Wetland Characteristics and Hydro Rankings*

I examined whether wetland characteristics (Table 2) varied with the frequency of water management impacts (hydro rankings) using Kruskal-Wallis tests and with region (stations with a hydro ranking of 3 in the West Kootenay and Columbia Wetlands) using Wilcoxon ranked-sum tests in R Studio (R Core Team 2018). Non-parametric tests were used as the data were not normally distributed (Shapiro-Wilk normality tests all $p<0.05$).

The Columbia Wetlands generally represent high-quality marsh habitat for our focal species and can be considered both a reference for unimpacted wetland conditions and a landscape-level control for comparing hydrological influences on marsh bird populations. All stations in the Columbia Wetlands have been assigned the hydro ranking of 3 (never impacted) but there are biogeophysical differences between the regions. If marsh bird densities and/or wetland characteristics are similar between hydro rank 3 stations in both regions, it could suggest that differences between hydro rankings may be related to the hydrological differences I am examining.

### *Occupancy Modelling*

I examined wetland occupancy of American coot, pied-billed grebe, sora, and Virginia rail using occupancy models implemented in Presence software version 2.12.24 (Hines 2006). American bittern detections in this study were too few to reliably model occupancy. Presence software uses species detection histories and wetland variables to estimate probabilities of station occupancy (psi) while accounting for detection (p). Three major considerations make occupancy models the ideal means of analyzing this dataset. First, this dataset has a large number of surveys with no detections. For example, sora was the most common species in this study yet was only detected in about one third of the surveys and half of those detections were of a single individual. Therefore, surveys produced zero-inflated, right-tailed distributions for each species. Second, stations were visited multiple times each season, producing a detection history in addition to a count. Third, secretive marsh birds are by nature inconspicuous and detection is likely imperfect. Repeated visits and broadcast-callback techniques can improve detection considerably (Gibbs and Melvin 1993, Conway and Gibbs 2005), but imperfect detection can still be a challenge when examining these species. Given the zero-inflated nature of our data, multiple station visits, and implicit incorporation of detection into the model, I concluded that occupancy modelling was the most appropriate approach. Occupancy modelling considers presence/not-detected observations across multiple visits to model site occupancy as a function of the probability of occupancy and detection. An alternative method would have been a GLMM with a negative binomial or Poisson distribution (Dénes et al. 2015), however, occupancy modelling allows us to better utilize the multiple visits conducted and to explicitly incorporate species detectability into the model.

Occupancy modelling was completed in three steps: 1) modelling detection probability (p) as a function of seasonal timing, 2) modelling occupancy (psi) as a function of hydro ranking, year, and region, and 3) modelling occupancy (psi) as a function of wetland variables. At each stage models were ranked based on their AIC values and the model with the lowest AIC was selected to move into the next stage. Elevation and percent cover of open water, emergent vegetation, tall vegetation, and woody vegetation were standardized to a 0-10 scale, 10 being the highest observed value of a given variable. This was done by calculating a variable-specific constant, based on the maximum observed value of that variable, and multiplying all observations by this constant (Hines 2006). This permits variables to be considered on the same scale, simpler comparison of effect sizes, and straightforward conversion of beta values to the variables' original scale.

I tailored the models based on wetland characteristics that are biologically or ecologically relevant to these secretive marsh bird species (Table 1). A range of wetland characteristics were collected as part of this study and I first conducted a literature review to select a candidate set of variables (Table 2). To ensure highly correlated variables were not considered in the same model, I created a correlation matrix between all pairs of variables using R Studio (R Core Team 2018). Correlation matrices found a strong correlation ($r > 0.70$) between percent cover of emergent vegetation and open water, therefore these were not modelled together. Emergent and tall vegetation were also not modelled together, as tall vegetation is a subset of emergent (Table 2).

## 1.3. Results

### *Sampling Effort and Station Occupancy in Relation to Water Management Impacts*

In the West Kootenay surveys between 34 and 60 stations were surveyed for marsh birds each year, of which approximately 15% were always impacted by hydro development or water management operations (hydro rank 1), 20% were occasionally impacted (hydro rank 2), and 65% were never impacted (hydro rank 3; Table 3). In the Columbia Wetlands between 35 and 65 stations were surveyed each year, all of which are never impacted by hydro development or water management operations (Table 4).

American bittern was the least likely species to be detected in this study. American bittern were not detected at the West Kootenay stations between 2013 and 2018 (Table 3) and were only detected at 3-8% of stations in the Columbia Wetlands in any given year (Table 4). Defining a station as occupied if a bird was detected during at least one survey, sora was the most commonly detected species in both regions. Sora occupied (mean ± standard deviation) 40% ± 7% of stations in the West Kootenay and 74% ± 10% of stations in the Columbia Wetlands. Virginia rail were detected at nearly as many stations as sora in the West Kootenay, an average of 39% ± 4%, compared to 27% ± 4% of stations in the Columbia Wetlands. American coot occupied a similar number of stations in both regions, 24% ± 6% in the West Kootenay and 30% ± 15% in the Columbia Wetlands. Pied-billed grebe, however, occupied more than triple the number of stations in the Columbia Wetlands (63% ± 12%) as they did in the West Kootenay (19% ± 7%). Occupancy of all four species was higher at less frequently impacted stations (Table 3, Figure 2). All four species occupy stations which are either occasionally or never impacted at higher frequencies than stations which are always impacted (Figure 2).

*Table 3. Summary of stations, survey effort, occupancy, and number of detections by year and hydro ranking in the West Kootenay. Stations occupied summarizes the percentage of stations where a minimum of one bird was detected during one survey and in brackets are the total number of birds detected. Survey effort denotes the total number of surveys conducted in a given category. Hydro rankings are categorized as follows: 1 = station is always impacted by water management operations, 2 = station is occasionally impacted, 3 = station is never impacted. American bittern was not observed within this time period, therefore is not included in this summary.*

| Year / Hydro | Rank | Stations | Survey Effort | % Stations Occupied (Number of Detections) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | American coot | | Pied-billed grebe | | Sora | | Virginia rail | |
| 2013 | 1 | 9 | 24 | 11 | (4) | 11 | (1) | 22 | (2) | 0 | (0) |
| | 2 | 17 | 40 | 47 | (364) | 76 | (47) | 59 | (32) | 53 | (23) |
| | 3 | 34 | 95 | 24 | (34) | 12 | (7) | 35 | (39) | 41 | (41) |
| | Total | 60 | 159 | 28 | (402) | 30 | (55) | 40 | (73) | 38 | (64) |
| 2014 | 1 | 9 | 27 | 11 | (1) | 11 | (2) | 44 | (6) | 0 | (0) |
| | 2 | 7 | 21 | 57 | (40) | 71 | (16) | 57 | (17) | 71 | (16) |
| | 3 | 37 | 103 | 19 | (28) | 5 | (4) | 27 | (44) | 35 | (51) |
| | Total | 53 | 151 | 23 | (69) | 15 | (22) | 34 | (67) | 34 | (67) |
| 2015 | 1 | 9 | 26 | 0 | (0) | 0 | (0) | 33 | (9) | 11 | (6) |
| | 2 | 7 | 20 | 43 | (7) | 29 | (2) | 86 | (33) | 43 | (17) |
| | 3 | 37 | 106 | 14 | (29) | 19 | (19) | 35 | (48) | 46 | (83) |
| | Total | 53 | 152 | 15 | (36) | 17 | (21) | 42 | (90) | 40 | (106) |
| 2017 | 1 | 5 | 15 | 20 | (2) | 0 | (0) | 40 | (3) | 40 | (4) |
| | 2 | 10 | 27 | 50 | (70) | 40 | (13) | 80 | (30) | 30 | (6) |
| | 3 | 28 | 84 | 21 | (22) | 11 | (11) | 39 | (58) | 50 | (51) |
| | Total | 43 | 126 | 28 | (94) | 16 | (24) | 49 | (91) | 44 | (61) |
| 2018 | 1 | 5 | 15 | 0 | (0) | 0 | (0) | 20 | (5) | 40 | (2) |
| | 2 | 7 | 21 | 57 | (54) | 14 | (8) | 100 | (33) | 57 | (14) |
| | 3 | 22 | 64 | 23 | (28) | 14 | (7) | 14 | (23) | 36 | (36) |
| | Total | 34 | 100 | 26 | (82) | 12 | (15) | 32 | (61) | 41 | (52) |
| Average | 1 | 7 | 21 | 8 | (1) | 5 | (1) | 32 | (5) | 14 | (2) |
| | 2 | 10 | 26 | 50 | (107) | 52 | (17) | 73 | (29) | 50 | (15) |
| | 3 | 32 | 90 | 20 | (28) | 12 | (10) | 31 | (42) | 42 | (52) |
| | Total | 49 | 138 | 24 | (137) | 19 | (27) | 40 | (76) | 39 | (70) |

*Table 4. Summary of stations, survey effort, occupancy, and number of detections by year in the Columbia Wetlands. Stations occupied summarizes the percentage of stations where a minimum of one bird was detected during one survey and in brackets are the total number of birds detected. Survey effort denotes the total number of surveys conducted in a given category. All stations have a hydro ranking of 3, i.e. the stations are never impacted by water management and/or hydro operations.*

| Year | Stations | Survey Effort | % Stations Occupied (Number of Detections) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | American bittern | | American coot | | Pied-billed grebe | | Sora | | Virginia rail | |
| 2016 | 35 | 100 | 3 | (1) | 46 | (109) | 77 | (108) | 86 | (151) | 26 | (11) |
| 2017 | 58 | 171 | 3 | (7) | 16 | (35) | 66 | (127) | 67 | (122) | 31 | (38) |
| 2018 | 65 | 191 | 8 | (10) | 33 | (94) | 54 | (107) | 73 | (165) | 24 | (37) |
| Average | 53 | 154 | 5 | (6) | 30 | (79) | 63 | (114) | 74 | (146) | 27 | (29) |

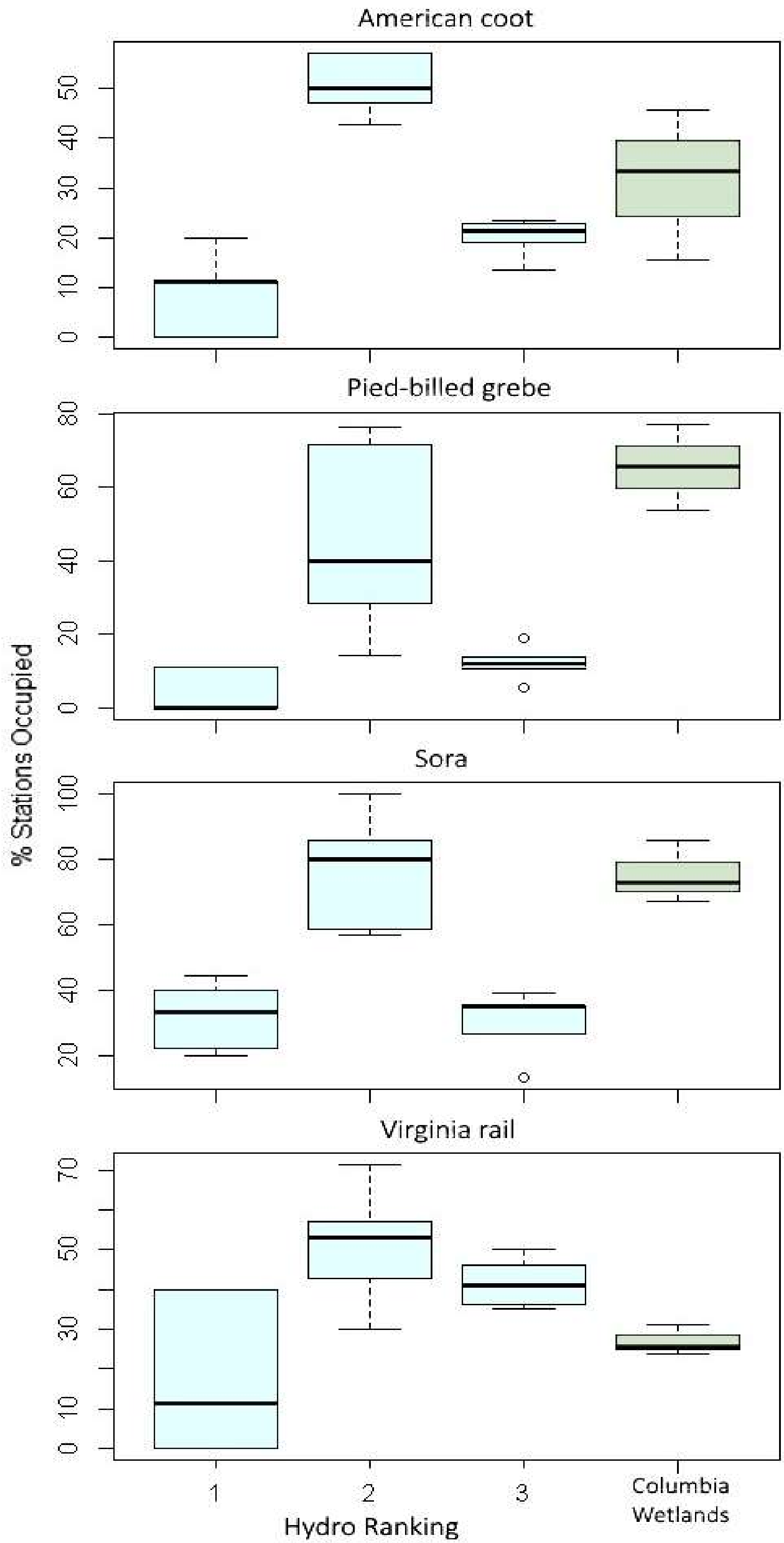



*Figure 2. Box plots depicting percent of stations occupied by region and hydro ranking for each species. Stations in the West Kootenay are separated by hydro ranking which are categorized as follows: 1 = station is always impacted by water management operations, 2 = station is occasionally impacted, and 3 = station is never impacted. Columbia Wetlands stations are all hydro rank 3 and are included as reference.*

## Marsh Bird Densities in Relation to Region and Water Management Impacts

American coot, pied-billed grebe, sora, and Virginia rail occurred in higher densities at stations which were less frequently impacted by water management projects (Table 5, Figure 3). American bittern were not observed in the West Kootenay in recent years, therefore density estimates were only completed for the Columbia Wetlands (Table 6). Within the West Kootenay, densities of pied-billed grebe and American coot were highest at stations which are occasionally impacted; sora had similar densities between stations which are sometimes and never impacted; and Virginia rail were at their highest densities at stations which are never impacted (Figure 3). Comparing stations which are never impacted (hydro ranking 3) between regions, densities of pied-billed grebe were higher in the Columbia Wetlands; densities of American coot and sora were similar between regions; and densities of Virginia rail were higher in the West Kootenay (Tables 5 and 6, Figure 3). There was some year-to-year variation, particularly in 2013 for all four species and 2015 for American coot and pied-billed grebe (Table 5).

*Table 5. Density estimates (individuals/hectare) with standard error for four focal marsh bird species in the West Kootenay summarized by hydro ranking and year. Hydro rankings are categorized as follows: 1 = station is always impacted by water management, 2 = station is occasionally impacted, 3 = station is never impacted.*

| Year / Hydro Rank | | American coot | Pied-billed grebe | Sora | Virginia rail |
|---|---|---|---|---|---|
| 2013 | 1 | 0.30 ± 0.23 | 0.22 ± 0.22 | 0.05 ± 0.05 | 0.00 ± 0.00 |
| | 2 | 0.98 ± 0.92 | 0.16 ± 0.05 | 0.30 ± 0.09 | 0.25 ± 0.08 |
| | 3 | 0.17 ± 0.04 | 0.02 ± 0.01 | 0.25 ± 0.06 | 0.39 ± 0.09 |
| 2014 | 1 | 0.20 ± 0.20 | 0.02 ± 0.02 | 0.03 ± 0.02 | 0.00 ± 0.00 |
| | 2 | 0.64 ± 0.43 | 0.09 ± 0.05 | 0.25 ± 0.10 | 0.23 ± 0.10 |
| | 3 | 0.10 ± 0.03 | 0.01 ± 0.01 | 0.24 ± 0.06 | 0.62 ± 0.13 |
| 2015 | 1 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.08 ± 0.05 | 0.16 ± 0.10 |
| | 2 | 0.34 ± 0.19 | 0.00 ± 0.01 | 0.31 ± 0.10 | 0.54 ± 0.20 |
| | 3 | 0.44 ± 0.30 | 0.04 ± 0.02 | 0.25 ± 0.05 | 0.70 ± 0.11 |
| 2017 | 1 | 0.08 ± 0.08 | 0.00 ± 0.00 | 0.01 ± 0.01 | 0.14 ± 0.11 |
| | 2 | 0.58 ± 0.28 | 0.09 ± 0.05 | 0.32 ± 0.10 | 0.11 ± 0.07 |
| | 3 | 0.13 ± 0.04 | 0.01 ± 0.01 | 0.25 ± 0.05 | 0.41 ± 0.09 |
| 2018 | 1 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.24 ± 0.16 | 0.08 ± 0.08 |
| | 2 | 0.66 ± 0.41 | 0.21 ± 0.12 | 0.33 ± 0.10 | 0.41 ± 0.17 |
| | 3 | 0.19 ± 0.13 | 0.01 ± 0.01 | 0.10 ± 0.03 | 0.49 ± 0.12 |
| Average | 1 | 0.12 ± 0.10 | 0.05 ± 0.05 | 0.08 ± 0.06 | 0.08 ± 0.06 |
| | 2 | 0.64 ± 0.45 | 0.11 ± 0.05 | 0.30 ± 0.10 | 0.31 ± 0.12 |
| | 3 | 0.20 ± 0.11 | 0.02 ± 0.01 | 0.22 ± 0.05 | 0.52 ± 0.11 |

*Table 6. Density estimates (individuals/hectare) with standard error in the Columbia Wetlands for five focal marsh bird species summarized by year.*

| Year | American bittern | American coot | Pied-billed grebe | Sora | Virginia rail |
|---|---|---|---|---|---|
| 2016 | 0.05 ± 0.05 | 0.29 ± 0.12 | 0.11 ± 0.02 | 0.37 ± 0.05 | 0.04 ± 0.02 |
| 2017 | 0.02 ± 0.01 | 0.06 ± 0.04 | 0.07 ± 0.01 | 0.10 ± 0.02 | 0.09 ± 0.02 |
| 2018 | 0.03 ± 0.01 | 0.25 ± 0.10 | 0.10 ± 0.02 | 0.20 ± 0.03 | 0.13 ± 0.03 |
| Average | 0.03 ± 0.03 | 0.20 ± 0.09 | 0.09 ± 0.02 | 0.22 ± 0.03 | 0.09 ± 0.02 |

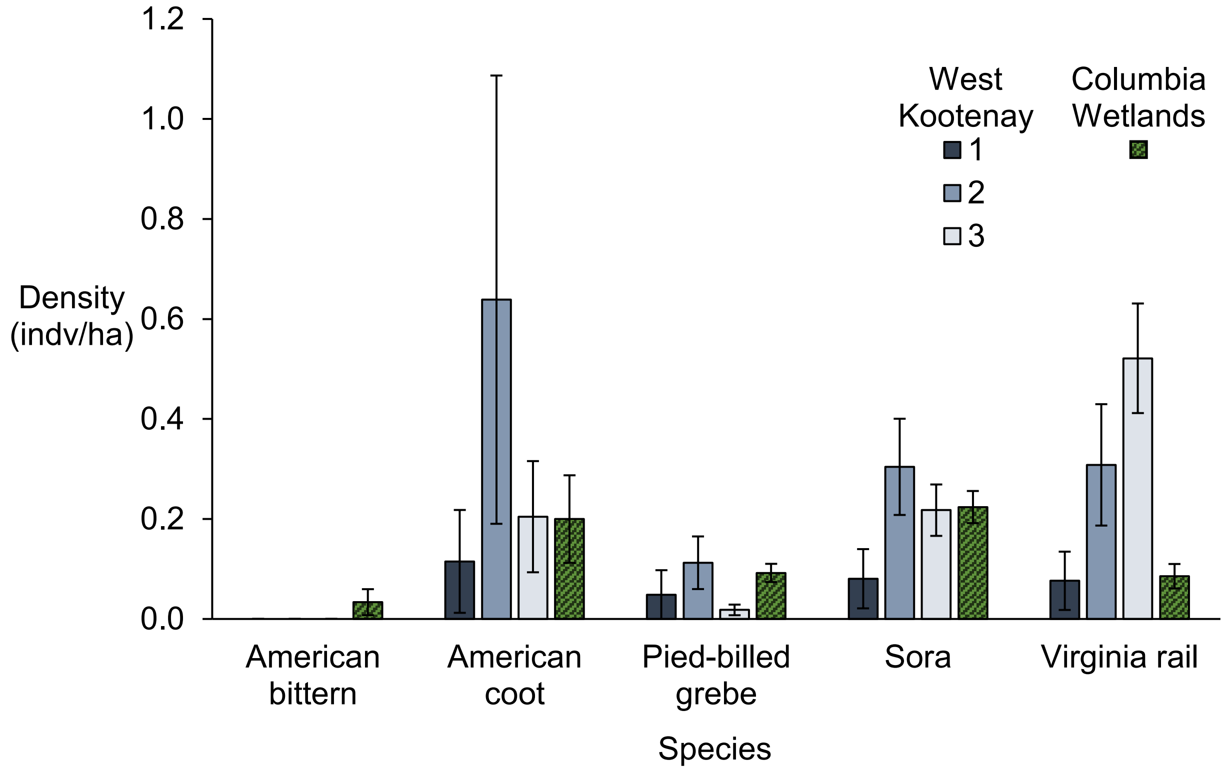



*Figure 3. Density estimates (individuals/hectare) with standard error of five focal marsh bird species by hydro ranking and region. Columbia Wetlands stations are all hydro rank 3 and densities in this region are included as reference. Hydro rankings are categorized as follows: 1 = station is always impacted by water management operations, 2 = station is occasionally impacted, 3 = station is never impacted.*

## Wetland Characteristics in Relation to Region and Water Management Impacts

I found that wetland characteristics (Table 2) varied with the frequency of water management impacts and, to some extent, between regions. All wetland characteristics apart from tall vegetation differed significantly between hydro rankings in the West Kootenay (Table 7, Figure 4). Open water cover was highest at stations which are always impacted by water management operations; emergent and tall vegetation cover were both highest at stations which are occasionally impacted; and woody vegetation cover was highest at stations which are never impacted (Figure 4). Between regions, the relative percent cover of water and emergent vegetation was not significantly different, but woody and tall vegetation cover were both higher at the Columbia Wetlands stations (Table 7, Figure 4). Relative percent cover of open water significantly predicted that of emergent vegetation in both regions (West Kootenay: -0.77 ± 0.07, $t_{54}$ = -10.38, $p$<0.0001; Columbia Wetlands: -0.91 ± 0.05, $t_{66}$ = -19.62, $p$<0.0001) and woody vegetation in the West Kootenay (-0.20 ± 0.07, $t_{54}$ = -2.24, $p$=0.005; Columbia Wetlands: -0.07 ± 0.04, $t_{66}$ = -1.58 $p$=0.12).

*Table 7. Comparing wetland characteristics between hydro rankings in the West Kootenay (Kruskal-Wallis tests) and stations which are never impacted (hydro rank 3) in both regions (Wilcoxin rank sum tests).*

| Variable | | Test statistic | | df | p-value |
|---|---|---|---|---|---|
| Water | | | | | |
| | Hydro Ranking | $\chi^2$ = | 11.98 | 2 | 0.003 |
| | Region | W = | 1142 | 1 | 0.384 |
| Woody | | | | | |
| | Hydro Ranking | $\chi^2$ = | 12.21 | 2 | 0.002 |
| | Region | W = | 956 | 1 | 0.034 |
| Emergent | | | | | |
| | Hydro Ranking | $\chi^2$ = | 8.72 | 2 | 0.013 |
| | Region | W = | 1486 | 1 | 0.157 |
| Tall | | | | | |
| | Hydro Ranking | $\chi^2$ = | 3.46 | 2 | 0.177 |
| | Region | W = | 793 | 1 | 0.001 |

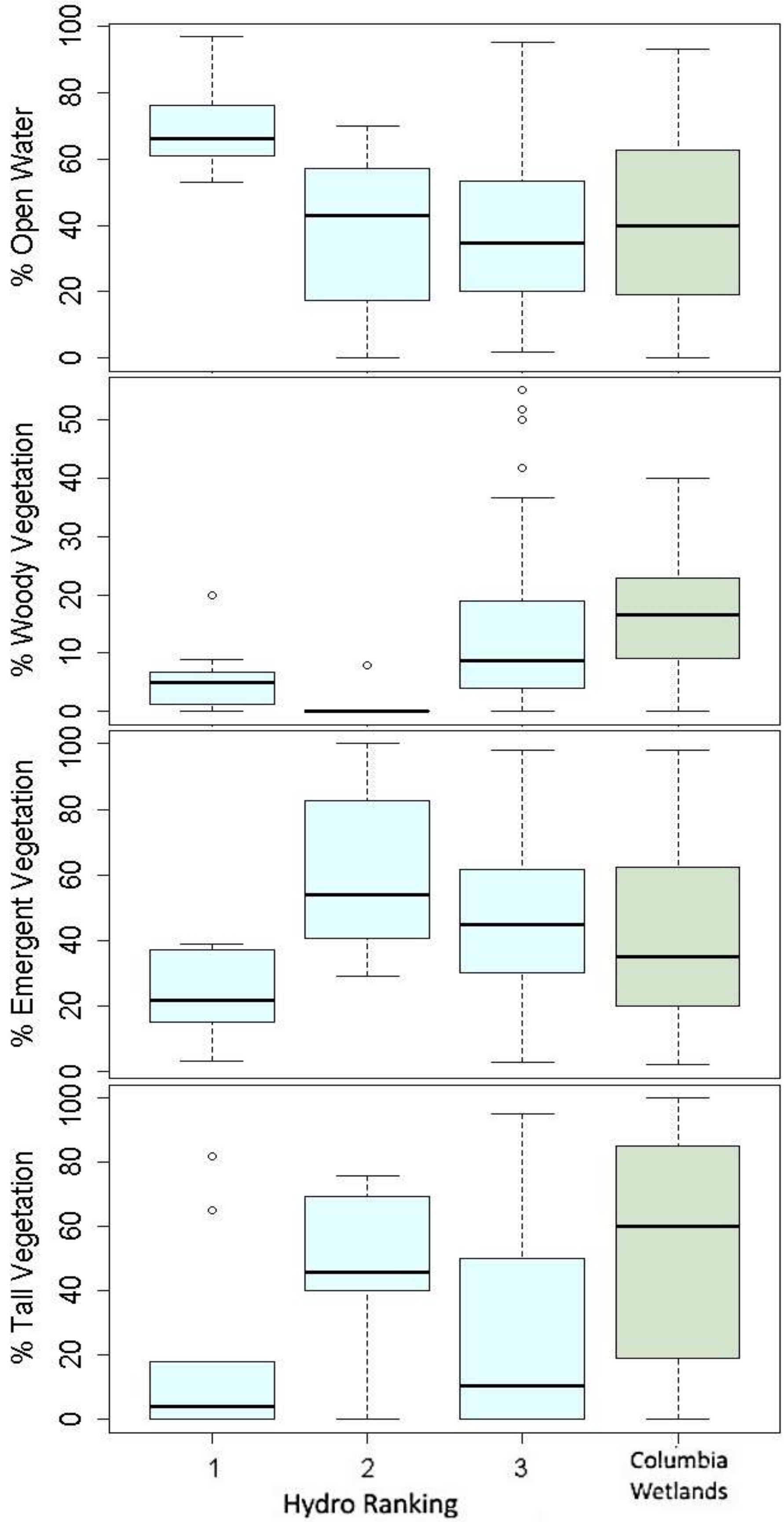



*Figure 4. Box plots depicting relative percent cover wetland characteristics at survey stations. Stations in the West Kootenay are partitioned by hydro rankings which are categorized as follows: 1 = station is always impacted by water management operations, 2 = station is occasionally impacted, 3 = station is never impacted. Columbia Wetlands stations are all hydro rank 3 and are included as reference. Note: tall vegetation is a subset of emergent vegetation.*

## Secretive Marsh Bird Occupancy Models

I used occupancy models to examine the presence of American coot, pied-billed grebe, sora, and Virginia rail in the West Kootenay and Columbia Wetlands. Detection of all four species was best modelled as a function of survey date in either linear or quadratic form. The final models of all four species highlighted open water, woody vegetation, and elevation as being important contributing factors for station occupancy, and three of the four species highlighted tall vegetation as well. Effect sizes are given on the logit-scale and suggest that elevation has the largest impact on marsh bird occupancy for all four species followed by woody vegetation cover for American coot, pied-billed grebe, and sora, and open water cover for Virginia rail.

### *American Coot*

Occupancy models examining the presence of American coot at stations in the West Kootenay and Columbia Wetlands were best modelled with the probability of detection as a linear function of survey date (logit-scale beta ± standard error: -0.03 ± 0.01; Table 8). The odds of American coot being detected on 1 May were nearly seven times higher than on 1 July (odds ratio [OR] = 6.87). After controlling for detection, the best model suggested that there were regional differences in station occupancy (-2.00 ± 0.52) with American coot more likely to occupy a station in the Columbia Wetlands compared to the West Kootenay. Regional differences remained after accounting for wetland characteristics (Table 8). American coot were more likely to occupy stations at lower elevations (-0.96 ± 0.22) with less open water (-0.19 ± 0.06), less woody vegetation (-0.49 ± 0.13), and more tall vegetation (0.17 ± 0.05). The strength of the standardized effect sizes suggests that elevation followed by woody vegetation cover have the largest impact on American coot occupancy (Figure 5).

*Table 8. Summary of three sequential occupancy modelling stages for American coot. For the final stage, shown are the top five supported and the base models. Complete model results are summarized in Appendix D. Probability of occupancy is denoted with "psi" and probability of detection is denoted with "p".*

| Model | AIC | ΔAIC | Akaike Weight ($w_i$) | K |
|---|---|---|---|---|
| ***Detection (p)*** | | | | |
| Psi(year + hydro + region), p(day) | 785.24 | 0.00 | 0.67 | 6 |
| Psi(year + hydro + region), p(day + day2) | 786.66 | 1.42 | 0.33 | 7 |
| Psi(year + hydro + region), p(.) | 802.07 | 16.83 | 0.00 | 5 |
| ***Occupancy (psi) - Region, Year, Hydro Ranking*** | | | | |
| Psi(region), p(day) | 781.46 | 0.00 | 0.37 | 4 |
| Psi(.), p(day) | 781.64 | 0.18 | 0.34 | 3 |
| Psi(hydro), p(day) | 783.32 | 1.86 | 0.15 | 4 |
| Psi(year), p(day) | 783.41 | 1.95 | 0.14 | 4 |
| ***Occupancy (psi) - Wetland Characteristics*** | | | | |
| Psi(region + water + woody + tall + elevation), p(day) | 675.70 | 0.00 | 0.93 | 8 |
| Psi(region + woody + elevation + emergent), p(day) | 681.76 | 6.06 | 0.05 | 7 |
| Psi(region + woody + elevation + tall), p(day) | 684.10 | 8.40 | 0.01 | 7 |
| Psi(region + water + woody + elevation), p(day) | 685.78 | 10.08 | 0.01 | 7 |
| Psi(water + woody + tall + elevation), p(day) | 691.58 | 15.88 | 0.00 | 7 |
| Psi(tall), p(day) | 726.30 | 50.60 | 0.00 | 4 |
| Psi(elevation), p(day) | 746.27 | 70.57 | 0.00 | 4 |
| Psi(woody), p(day) | 754.40 | 78.70 | 0.00 | 4 |
| Psi(water), p(day) | 780.37 | 104.67 | 0.00 | 4 |
| Psi(region), p(day) | 781.46 | 105.76 | 0.00 | 4 |
| Psi(.), p(day) | 781.64 | 105.94 | 0.00 | 3 |

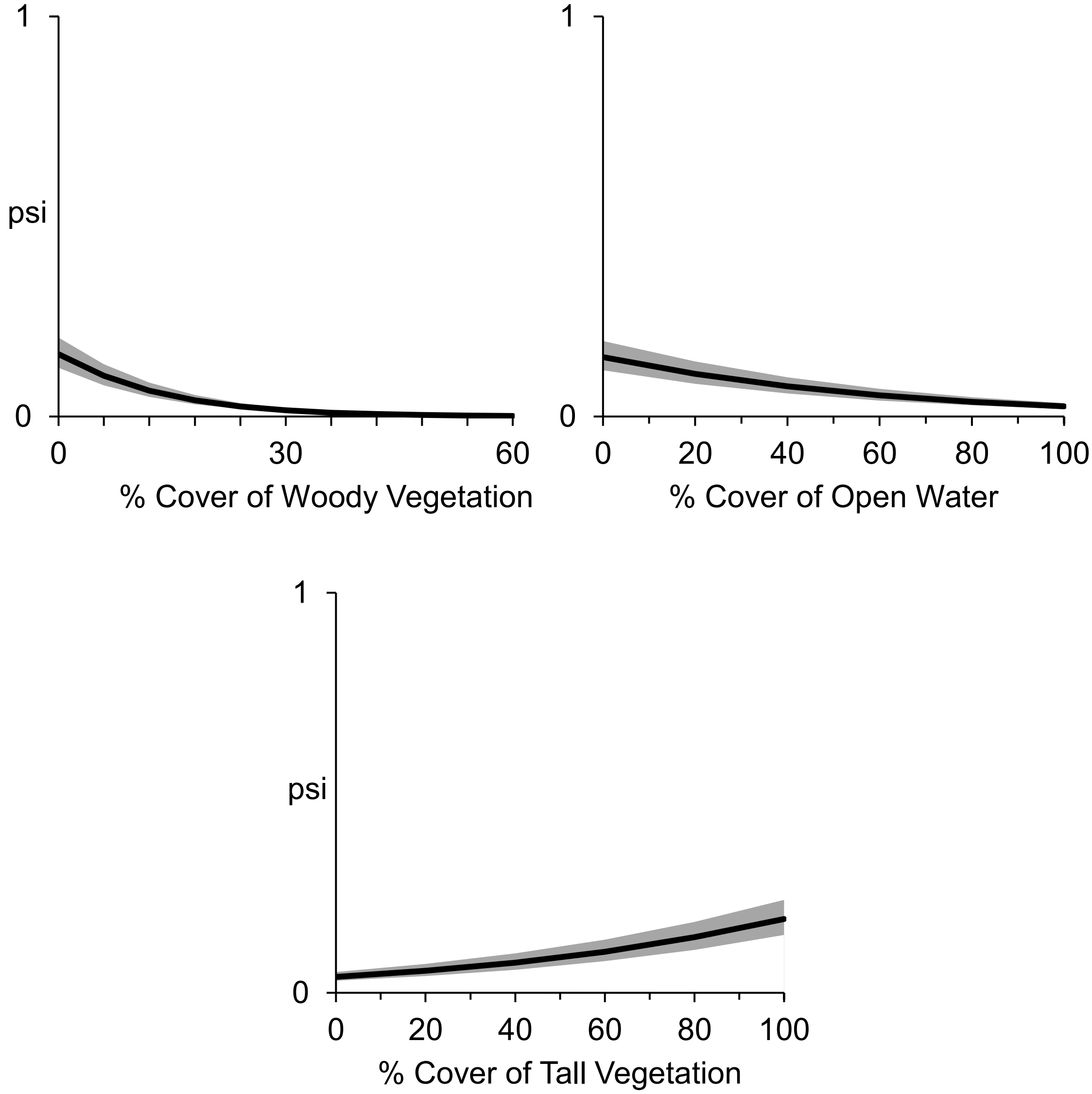



*Figure 5. Plots depicting the relationship between the probability of American coot occupancy (psi) and wetland characteristics in the West Kootenay. Plots are based on the top model predicting occupancy of American coot, where psi = intercept + region + water + woody + tall + elevation (Table 8) and examine psi as a function of the percent cover of woody vegetation (top-left), open water (top-right), or tall vegetation (bottom). Plots assume region = West Kootenay (1) and the remaining variables are at the median observed value in this study. The x-axis reflects the maximum observed value of the wetland characteristic of interest. Shaded areas depict a 95% confidence interval.*

### *Pied-billed Grebe*

Occupancy models examining the presence pied-billed grebes at stations in the West Kootenay and Columbia Wetlands were best modelled with the probability of detection as a quadratic function of survey date (day: 0.12 ± 0.01, $day^2$: -0.002 ± 0.0001; Table 9). The probability of detecting pied-billed grebe increased until a peak around 6 and 7 June before declining for the remainder of the season. After controlling for detection, the best model suggested that there were regional (-4.63 ± 0.66) and annual (-0.28 ± 0.12) differences in station occupancy. Pied-billed grebes were more likely to occupy stations in the Columbia Wetlands compared to the West Kootenay and were less likely to occupy a station with each passing year. Regional and annual differences remained after accounting for wetland characteristics (Table 9). Pied-billed grebe were more likely to occupy stations at lower elevations (-0.73 ± 0.20) with less open water (-0.14 ± 0.06), less woody vegetation (-0.44 ± 0.13), and more tall vegetation (0.23 ± 0.05). The strength of the standardized effect sizes suggests that elevation followed by woody vegetation cover have the largest impact on pied-billed grebe occupancy (Figure 6).

*Table 9. Summary of three sequential occupancy modelling stages for pied-billed grebe. For the final stage, shown are the top five supported, the top model with wetland characteristics alone, and the base models. Probability of occupancy is denoted with "psi" and probability of detection is denoted with "p". Complete model results are summarized in Appendix D.*

| Model | AIC | ΔAIC | Akaike Weight ($w_i$) | K |
|---|---|---|---|---|
| ***Detection (p)*** | | | | |
| Psi(year + hydro + region), p(day + day$^2$) | 914.93 | 0.00 | 1.00 | 7 |
| Psi(year + hydro + region), p(.) | 927.36 | 12.43 | 0.00 | 5 |
| Psi(year + hydro + region), p(day) | 927.65 | 12.72 | 0.00 | 6 |
| ***Occupancy (psi) - Region, Year, Hydro Ranking*** | | | | |
| Psi(region + year), p(day + day$^2$) | 913.38 | 0.00 | 0.35 | 6 |
| Psi(region), p(day + day$^2$) | 913.49 | 0.11 | 0.33 | 5 |
| Psi(year + hydro + region), p(day + day$^2$) | 914.93 | 1.55 | 0.16 | 7 |
| Psi(region + hydro), p(day + day$^2$) | 915.06 | 1.68 | 0.15 | 6 |
| Psi(hydro + year), p(day + day$^2$) | 974.03 | 60.65 | 0.00 | 6 |
| Psi(year), p(day + day$^2$) | 977.30 | 63.92 | 0.00 | 5 |
| Psi(hydro), p(day + day$^2$) | 986.03 | 72.65 | 0.00 | 5 |
| Psi(.), p(day + day$^2$) | 993.84 | 80.46 | 0.00 | 4 |
| ***Occupancy (psi) - Wetland Characteristics*** | | | | |
| Psi(region + year + water + woody + tall + elevation), p(day + day$^2$) | 820.61 | 0.00 | 0.85 | 10 |
| Psi(region + year + woody + tall + elevation), p(day + day$^2$) | 824.14 | 3.53 | 0.15 | 9 |
| Psi(region + year + tall + elevation), p(day + day$^2$) | 833.50 | 12.89 | 0.00 | 8 |
| Psi(region + year + water + tall + elevation), p(day + day$^2$) | 834.16 | 13.55 | 0.00 | 9 |
| Psi(region + year + water + woody + tall), p(day + day2) | 837.88 | 17.27 | 0.00 | 9 |
| Psi(water + woody + tall + elevation),p(day + day2) | 910.95 | 90.34 | 0.00 | 8 |
| Psi(tall), p(day + day$^2$) | 906.11 | 85.50 | 0.00 | 5 |
| Psi(region + year), p(day + day$^2$) | 913.38 | 92.77 | 0.00 | 6 |
| Psi(elevation), p(day + day$^2$) | 986.43 | 165.82 | 0.00 | 5 |
| Psi(woody), p(day + day$^2$) | 991.96 | 171.35 | 0.00 | 5 |
| Psi(water), p(day + day$^2$) | 993.29 | 172.68 | 0.00 | 5 |
| Psi(.), p(day + day2) | 993.84 | 173.23 | 0.00 | 4 |

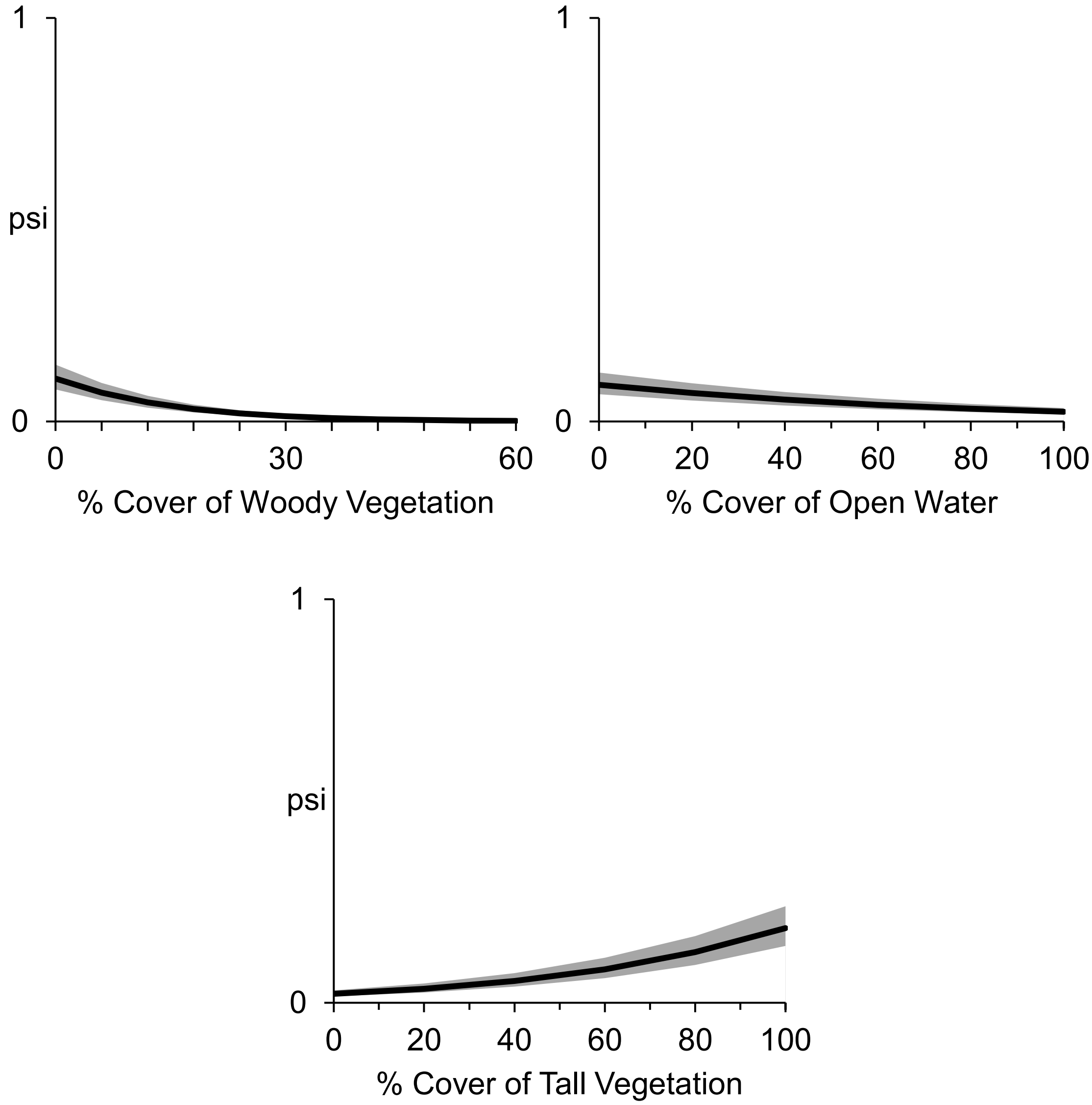



*Figure 6. Plots depicting the relationship between the probability of pied-billed grebe occupancy (psi) and wetland characteristics in the West Kootenay. Plots are based on the top model predicting occupancy of pied-billed grebe, where psi = intercept + region + year + water + woody + tall + elevation (Table 9) and examine psi as a function of the percent cover of woody vegetation (top-left), open water (top-right), or tall vegetation (bottom). Plots assume region = West Kootenay (1) and the remaining variables are at the median observed value in this study. The x-axis reflects the maximum observed value of the wetland characteristic of interest. Shaded areas depict a 95% confidence interval.*

### ***Sora***

Occupancy models examining the presence of sora at stations in the West Kootenay and Columbia Wetlands were best modelled with the probability of detection as a quadratic function of survey date (day: 0.05 ± 0.01, day$^2$: -0.001 ± 0.0001, Table 10). The probability of detecting sora increased until a peak around 6 June before declining for the remainder of the season. After controlling for detection, the best model suggested that there were regional differences in station occupancy (-2.78 ± 0.34) with sora being more likely to occupy a station in the Columbia Wetlands compared to the West Kootenay. Regional differences remained after accounting for wetland characteristics (Table 10). Sora were more likely to occupy stations at lower elevations (-0.59 ± 0.10) with less open water (-0.32 ± 0.06) and woody vegetation (-0.36 ± 0.08). Two other models also have good support (>2 ΔAIC), these models incorporated tall vegetation and emergent vegetation respectively. The strength of the standardized effect sizes suggests that elevation followed by woody vegetation cover have the largest impact on sora occupancy (Figure 7).

*Table 10. Summary of three sequential occupancy modelling stages for sora. For the final stage, shown are the top five supported, the top model with wetland characteristics alone, and the base models. Probability of occupancy is denoted with "psi" and probability of detection is denoted with "p". Complete model results summarized in Appendix D.*

| Model | AIC | ΔAIC | Akaike Weight ($w_i$) | K |
|---|---|---|---|---|
| ***Detection (p)*** | | | | |
| Psi(year + hydro + region), p(day + day$^2$) | 1178.51 | 0.00 | 0.47 | 7 |
| Psi(year + hydro + region), p(.) | 1179.01 | 0.50 | 0.37 | 5 |
| Psi(year + hydro + region), p(day) | 1180.64 | 2.13 | 0.16 | 6 |
| ***Occupancy (psi) - Region, Year, Hydro Ranking*** | | | | |
| Psi(region), p(day + day$^2$) | 1179.21 | 0.00 | 0.66 | 5 |
| Psi(region + year), p(day + day$^2$) | 1180.57 | 1.36 | 0.34 | 6 |
| Psi(year), p(day + day$^2$) | 1217.23 | 38.02 | 0.00 | 5 |
| Psi(.), p(day + day$^2$) | 1226.99 | 47.78 | 0.00 | 4 |
| Psi(hydro), p(day + day$^2$) | 1228.21 | 49.00 | 0.00 | 5 |
| ***Occupancy (psi) - Wetland Characteristics*** | | | | |
| Psi(region + water + woody + elevation), p(day + day$^2$) | 1095.26 | 0.00 | 0.49 | 8 |
| Psi(region + water + woody + tall + elevation), p(day + day$^2$) | 1096.41 | 1.15 | 0.28 | 9 |
| Psi(region + woody + emergent + elevation), p(day + day$^2$) | 1097.01 | 1.75 | 0.21 | 8 |
| Psi(region + emergent + elevation), p(day + day$^2$) | 1101.26 | 6.00 | 0.02 | 7 |
| Psi(region + water + tall + elevation), p(day + day$^2$) | 1112.74 | 17.48 | 0.00 | 8 |
| Psi(region), p(day + day$^2$) | 1179.21 | 83.95 | 0.00 | 5 |
| Psi(water + woody + elevation), p(day + day$^2$) | 1185.77 | 90.51 | 0.00 | 7 |
| Psi(elevation), p(day + day$^2$) | 1206.07 | 110.81 | 0.00 | 5 |
| Psi(water), p(day + day$^2$) | 1218.34 | 123.08 | 0.00 | 5 |
| Psi(woody), p(day + day$^2$) | 1224.04 | 128.78 | 0.00 | 5 |
| Psi(.),p(day + day$^2$) | 1226.99 | 131.73 | 0.00 | 4 |

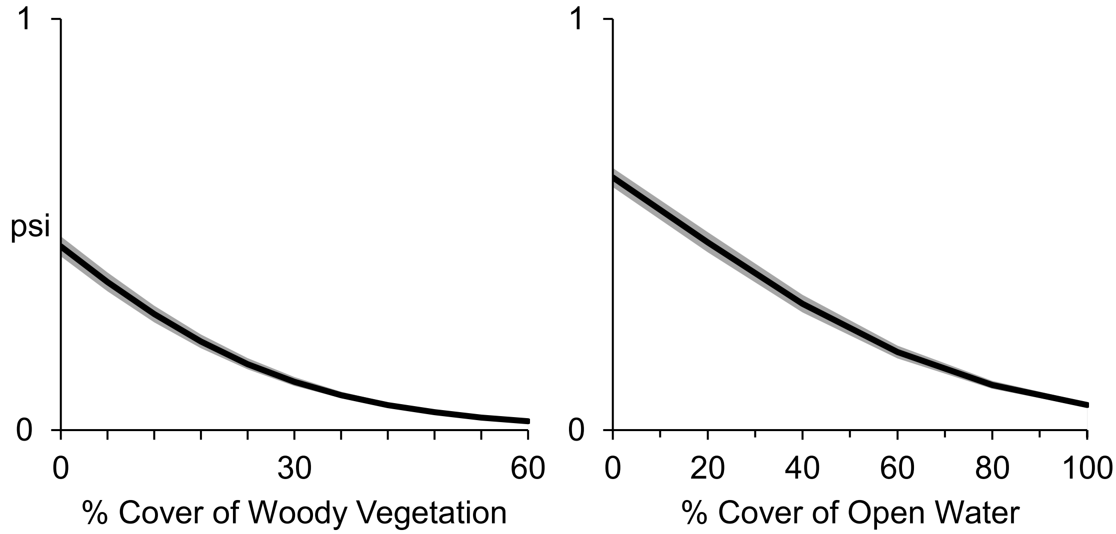



*Figure 7. Plots depicting the relationship between the probability of sora occupancy (psi) and wetland characteristics in the West Kootenay. Plots are based on the top model predicting occupancy of sora, where psi = intercept + region + water + woody + elevation (Table 10) and examine psi as a function of the percent cover of woody vegetation (left) or open water (right). Plots assume region = West Kootenay (1) and the remaining variables are at the median observed value in this study. The x-axis reflects the maximum observed value of the wetland characteristic of interest. Shaded areas depict a 95% confidence interval.*

### *Virginia Rail*

Occupancy models examining the presence of Virginia rail at stations in the West Kootenay and Columbia Wetlands were best modelled with the probability of detection as a quadratic function of survey date (day: 0.06 ± 0.02, day$^2$: -0.001 ± 0.0004, Table 11). The probability of detecting Virginia rail increased until a peak around 24 and 25 June before declining for the remainder of the season. Subsequent models failed to converge when modelling the probability of detection as a quadratic function of survey date, therefore for the remaining stages models used a linear function of survey date (0.03 ± 0.01) with the odds of detecting Virginia rail being a little over five times higher at the end of the season compared to the beginning (OR = 5.35). After controlling for detection, the best model suggested that there were water management (1.11 ± 0.33) and regional (1.41 ± 0.37) differences in station occupancy. The odds of Virginia rail occupying a station being three times higher with each increase in hydro ranking (OR = 3.03) and they were more likely to occupy a station in the West Kootenay compared to the Columbia Wetlands. Regional and water management differences remained after accounting for wetland characteristics (Table 11). Virginia rail were more likely to occupy stations at lower elevations (-0.43 ± 0.13) with less open water (-0.35 ± 0.06), less woody vegetation (-0.20 ± 0.08), and more tall vegetation (0.26 ± 0.06). The strength of the standardized effect sizes suggests that elevation followed by open water cover have the largest impact on Virginia rail occupancy (Figure 8).

*Table 11. Summary of three sequential occupancy modelling stages for Virginia rail. For final stage, shown are the top five supported and the base models. Probability of occupancy is denoted with "psi" and probability of detection is denoted with "p". Complete model results are summarized in Appendix D.*

| Model | AIC | ΔAIC | Akaike Weight ($w_i$) | K |
|---|---|---|---|---|
| ***Detection (p)*** | | | | |
| Psi(year + hydro + region), p(day + $day^2$)[1] | 924.27 | 0.00 | 0.50 | 7 |
| Psi(year + hydro + region), p(day) | 924.30 | 0.03 | 0.50 | 6 |
| Psi(year + hydro + region), p(.) | 939.29 | 15.02 | 0.00 | 5 |
| ***Occupancy (psi) - Region, Year, Hydro Ranking*** | | | | |
| Psi(region + hydro), p(day) | 922.36 | 0.00 | 0.84 | 5 |
| Psi(region), p(day) | 926.73 | 4.37 | 0.09 | 4 |
| Psi(hydro), p(day) | 929.12 | 6.76 | 0.03 | 4 |
| Psi(.), p(day) | 929.50 | 7.14 | 0.02 | 3 |
| Psi(year), p(day) | 930.29 | 7.93 | 0.02 | 4 |
| ***Occupancy (psi) - Wetland Characteristics*** | | | | |
| Psi(region + hydro + water + woody + tall + elevation), p(day) | 806.04 | 0.00 | 0.91 | 9 |
| Psi(region + hydro + water + tall + elevation), p(day) | 810.86 | 4.82 | 0.08 | 8 |
| Psi(region + hydro + water + woody + tall), p(day) | 816.97 | 10.93 | 0.00 | 8 |
| Psi(region + hydro + water + tall), p(day) | 819.76 | 13.72 | 0.00 | 7 |
| Psi(water + woody + tall + elevation), p(day) | 826.91 | 20.87 | 0.00 | 7 |
| Psi(tall), p(day) | 876.89 | 70.85 | 0.00 | 4 |
| Psi(water), p(day) | 897.85 | 91.81 | 0.00 | 4 |
| Psi(elevation), p(day) | 912.18 | 106.14 | 0.00 | 4 |
| Psi(woody), p(day) | 919.99 | 113.95 | 0.00 | 4 |
| Psi(region + hydro), p(day) | 922.36 | 116.32 | 0.00 | 5 |
| Psi(.), p(day) | 929.50 | 123.46 | 0.00 | 3 |

[1] Later models failed to converge when using "day + $day^2$" to model detection

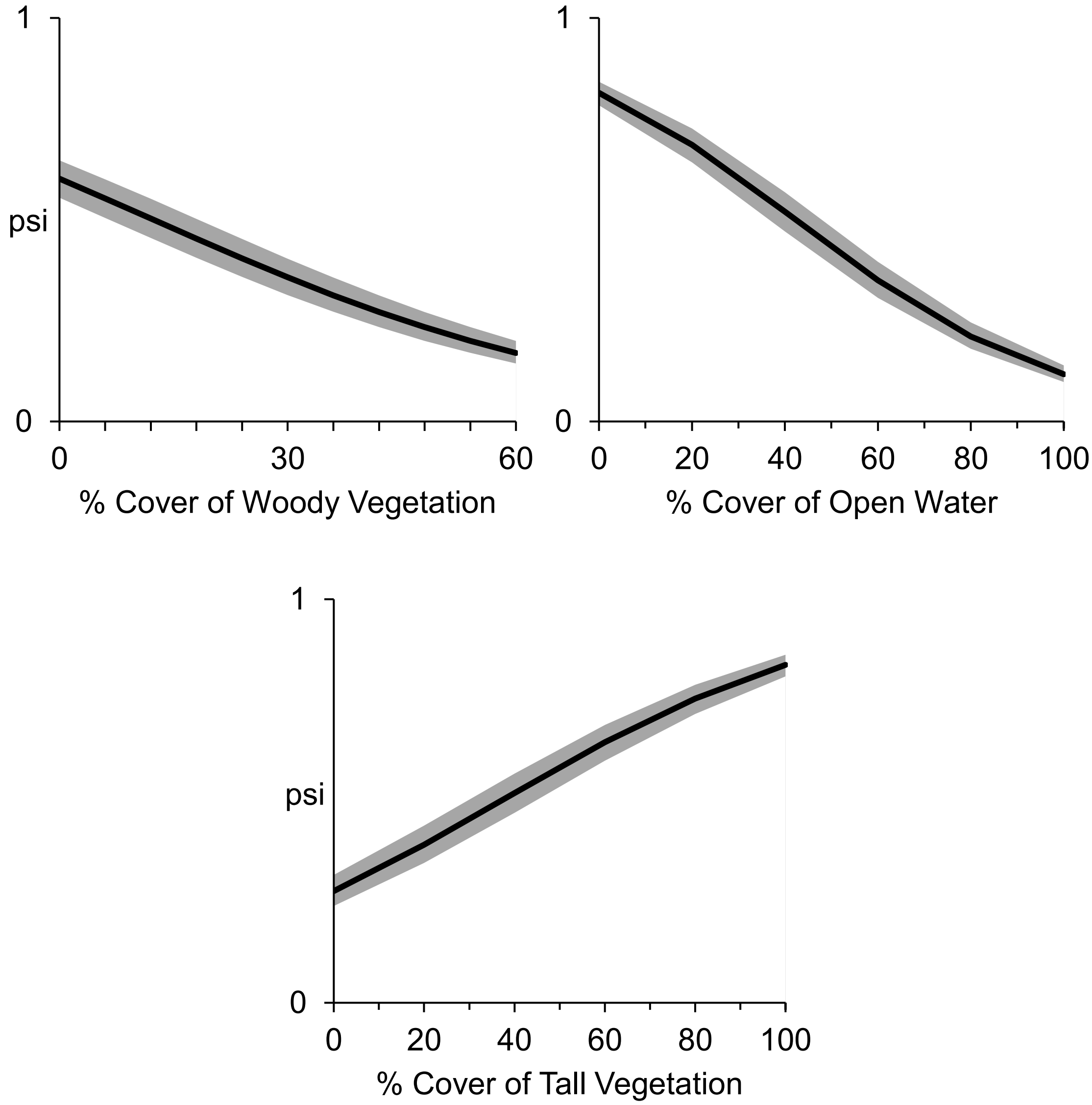



*Figure 8. Plots depicting the relationship between the probability of Virginia rail occupancy (psi) and wetland characteristics in the West Kootenay. Plots are based on the top model predicting occupancy of Virginia rail, where psi = intercept + region + hydro + water + woody + tall + elevation (Table 11) and examine psi as a function of the percent cover of woody vegetation (top-left), open water (top-right), or tall vegetation (bottom). Plots assume region = West Kootenay (1), hydro ranking = occasionally impacted (2), and the remaining variables are at the median observed value in this study. The x-axis reflects the maximum observed value of the wetland characteristic of interest. Shaded areas depict a 95% confidence interval.*

## 1.4. Discussion

Marsh birds may be affected by hydroelectric development and water management projects in ways that can be dynamic, complex, and site-specific. These effects can be the result of altered hydrological regimes (Hirst 1991, Utzig and Schmidt 2011), altered vegetation communities (Reitan and Thingstad 1999, Utzig and Schmidt 2011), and lost or altered habitat (Utzig and Schmidt 2011). Wetlands are often among the habitats most affected by water management projects, given their position in the watershed and propensity to regular flooding. Within the Columbia Basin, all five of our focal species have been identified as potentially suffering “very high” or “high” habitat-related impacts from hydro-related impacts in the Columbia Basin (Utzig and Schmidt 2011). Given the observational nature of this study, I cannot define cause-and-effect relationships between marsh bird populations and water management projects with certainty. I can, however, examine trends to inform restoration recommendations and conclusions. This study provides evidence that these species may be negatively influenced by water management activities. Vegetation communities differed with the frequency of water management impacts, with more frequently impacted wetlands associated with less emergent vegetation and more open water. These vegetation communities and wetland characteristics in turn influenced marsh bird occupancy. My results provide valuable insight for tailoring restoration and conservation initiatives to support marsh bird populations in wetlands affected by water management operations.

### Secretive Marsh Birds and Water Management Impacts

Population density and site occupancy for secretive marsh bird populations was influenced by the degree to which wetlands were affected by water management operations, though the patterns were not as expected. I initially predicted that population densities within the West Kootenay would decline with increasing frequency of water management impacts. As such, I also predicted that wetlands which were never impacted would have the highest population densities. This was based on the presumption that these wetlands would exhibit more natural assemblages and regimes that these bird species have co-evolved with, making them more desirable. I then predicted that wetlands which were frequently affected by water management operations would have fewer birds present. Interestingly, I found that the relationship between these species and water management impacts appears more nuanced.

The Columbia River is one of the most developed river systems in the world for water management projects (Toller and Nemetz 1997), projects which have promoted wetland loss within the Columbia Basin (Utzig and Schmidt 2011). Wetlands across the Columbia Basin, including those considered in this study, are important stop-over points within the Pacific Flyway. In general, I found that both study regions had comparable or greater frequency of American coot, pied-billed grebe, and sora compared to other North American wetlands (the prairie provinces: Baschuk et al. 2012, Tozer et al. 2016; Iowa: Harms and Dinsmore 2012; the Great Lakes-St. Lawrence region: Tozer et al. 2016). Virginia rail were detected at lower frequencies in the Columbia Wetlands compared to Iowa (Harms and Dinsmore 2012) but were more frequent in both study regions compared to the prairie provinces (Baschuk et al. 2012, Tozer et al. 2016) and the Great Lakes-St. Lawrence region (Tozer et al. 2016). The exception to this general trend was American bittern, which were relatively rare in this study and detected exclusively in the Columbia Wetlands. American bittern have been observed at greater frequencies in the prairies and, to some extent, the Great Lakes-St. Lawrence region (Tozer et al. 2016). They have also been present historically in the West Kootenay (Cooper and Beauchesne 2003) and are Blue-listed within British Columbia (BC CDC 1994b), making the lack of detections a cause for concern. While secretive marsh bird populations within the Columbia Basin may appear relatively robust compared to other regions, but they still occupy a precarious position being specialists of an ecosystem experiencing large-scale declines.

Secretive marsh birds had lower occupancy and population densities at the most frequently impacted stations (Figures 2 and 3). The results of this study suggest that these species are responding to proximate cues within the wetlands, including open water and vegetation composition (Tables 8-11) which differ with the frequency of water management impacts (Figure 4). Probability of occupancy of all four species was negatively associated by woody vegetation and open water, and for American coot, pied-billed grebe, and Virginia rail (and to a lesser degree, sora) were positively associated with tall vegetation (Tables 8-11). Stations which are always impacted by water management operations generally had the most open water and least tall vegetation cover (Figure 4), both of which were associated with lower probabilities of occupancy for these species (Tables 8-11). This was likely a strong driver of the lower occupancy and population densities observed at these stations (Figures 2 and 3). The relationship between marsh bird species and emergent vegetation cover is well-established (Forbes et al. 1989, Fairbairn and Dinsmore 2001, Lor and Malecki 2006, Darrah and Krementz 2009, Bolenbaugh et al. 2011, Baschuk et al. 2012). These marsh bird species, and many other marsh-specialists, rely on the emergent vegetation community to fill a variety of roles. Emergent vegetation provides important protective cover, nesting material (Gorenzel et al. 1982, Forbes et al. 1989), and sources of food (Horak 1970). In this study, tall vegetation examined cattails and rushes separately from the consideration of emergent vegetation as a whole. The dead stems of these species tend to persist over-winter and are often cited as providing nesting material and cover in the early spring before live material has established (Gorenzel et al. 1982, Forbes et al. 1989, Lor and Malecki 2006). Limited tall vegetation coupled with extensive open water may have deterred marsh birds from using the stations, especially in spring when they are likely searching for potential nesting sites with readily available nesting material and adequate protective cover.

A surprising result of this study was that American coot, pied-billed grebe, and sora occurred in higher densities at stations which are occasionally impacted by water management operations (Figure 3). Occupancy followed a similar pattern, the only distinction being that Virginia rail occupied a similar proportion of both occasionally and never impacted stations (Figure 2). Stations which are occasionally impacted are typically affected in years with higher than average water levels, i.e., years in which water levels are high enough to connect the wetland to a regulated waterway that it is not typically connected to. While these stations will occasionally experience an altered hydrological regime, it may not disturb the system to such an extent that it deters marsh bird occupancy or dramatically alters the vegetation community. In fact, these stations may have fewer extreme events as inundation would be moderated once water levels are high enough to connect to a managed waterway. For American coot, pied-billed grebe, and sora, the probability of occupancy was positively associated with tall vegetation and negatively affected by the percent cover of woody vegetation. Occasionally impacted stations appear to have the most favourable balance of these characteristics. These stations simultaneously have the most tall vegetation and least woody vegetation of the other stations (Figure 4). They also have less open water than stations which are always impacted. These stations would, therefore, have ample amounts of vegetative material and cover in early spring, likely making them appealing as nesting sites. Woody vegetation is thought to be negatively associated with these species possibly due to the increased perching sites and foraging areas woody vegetation creates for avian and mammalian predators (Naugle et al. 1999, Darrah and Krementz 2010). Occasionally impacted stations generally lacked woody vegetation and, therefore, lacked this negative cue. The combined abundance of tall vegetation and limited woody vegetation may create an ideal balance for these three species, promoting higher population densities and occupancy at stations which are occasionally impacted. Virginia rail was the exception and occurred at the highest densities at stations which are never impacted (Figures 2 and 3). Open water cover had the strongest effect on the probability of Virginia rail occupancy (Table 11, Figure 8), and open water cover decreased with decreasing frequency of water management impacts (Figure 4). This was likely the strong driving factor for the increased occupancy of Virginia rail at stations which are never impacted. Overall, these species appear to favour stations with a more natural hydrological regime, largely driven by a desirable balance of wetland characteristics at stations which are less frequently impacted.

The manner in which Virginia rail occupancy and density was influenced by the hydro rankings was unique, setting this species apart from American coot, pied-billed grebe, and sora. Following my initial predictions, Virginia rail densities increased with decreasing frequency of water management impacts (Figure 3). Virginia rail and sora share similar life history traits and co-occur more than expected by chance (Bolenbaugh et al. 2011), yet their patterns in occupancy and density diverged when stations were never impacted. While their densities were similar at more frequently impacted stations, at stations which are never impacted Virginia rail occurred at higher densities in the West Kootenay while densities of sora were similar in both regions (Figure 3). Population densities may be closely tied to the frequency of water management impacts and its associated effects, but additional factors appear to be driving Virginia rail populations that are not affecting sora to the same extent. The occupancy model for Virginia rail considered both hydro ranking and regional effects independent of other variables (Table 11). Citizen science data (eBird 2012) suggests that Virginia rail are more frequently detected within the interior of British Columbia, including the West Kootenay region of our study, yet are sporadically reported at low frequencies east of the

Rocky Mountains into Alberta (eBird 2012). The Columbia Wetlands may be on the eastern edge of their preferred range, hence Virginia rail may not be present in high densities. A second possibility may be related to differences in food availability. Where the diet of Virginia rail relies more heavily on invertebrates, seeds tend to dominate that of sora (Horak 1970). Food availability was not specifically addressed in this study, however differences in the availability of different food sources may influence their population distributions.

Hydrological regime is an important determinant of the physical, and ultimately biological, composition of aquatic and semi-aquatic ecosystems (Bunn and Arthington 2002). Altered flow and inundation can result in lost or modified habitat (Utzig and Schmidt 2011) and changes to vegetation communities (Blom and Voesenek 1996, Nilsson et al. 1997, Ellis et al. 2009, Campbell et al. 2016). In this study I found that relative percent cover of open water was negatively correlated with the emergent vegetation cover in both the West Kootenay and Columbia Wetlands. Emergent vegetation species adapted to wetland environments have varied degrees of tolerance to flooding. In fact, many plant species have evolved life history strategies which are dependent on seasonal flooding, such as floating seed dispersal mechanisms (Blom and Voesenek 1996, Seabloom et al. 1998). However, if cycles are too extreme it can limit plant survival and establishment, which could result in higher cover of open water with lower amounts of emergent vegetation. Extended, severe, and/or seasonally inappropriate periods of flooding can inhibit seed dispersal, increase seedling mortality, and alter the soil structure to such an extent that it inhibits growth (Blom and Voesenek 1996). Frequent flooding and water depth can alter the vegetation community to favour species with specific adaptations (Blom and Voesenek 1996, Seabloom et al. 1998), which may or may not be utilized by marsh bird species. Campbell et al. (2016) found a strong relationship between the duration of flooding and plant survival. They experimentally manipulated flooding conditions for ten common emergent vegetation species, including several species of sedges and grasses within the emergent vegetation category of this study. They found that survival was highest if flooding did not exceed 22% of the growing season and repeated seasons of sustained flooding reduced survival considerably (Campbell et al. 2016). In the West Kootenay, water management operations that increase the frequency, severity, and/or duration of inundation may therefore be driving the relationships I observed between hydro rankings, vegetation, and marsh bird densities.

The hydro ranking system in this study provides a description of how frequently we can expect the hydrological regime at a given station to differ from the regime it would naturally experience. Given that open water cover at stations which are never impacted did not differ significantly between regions (Table 7), my results suggest that the frequency of water management impacts does alter how much open water is present. This could be due to flooding occurring at the time of surveys and/or an impacted hydrological regime which prevents more vegetation from establishing at frequently impacted stations. This can be explored to some extent by examining the hydrological regime near the Duncan Dam Reservoir, a large water management project in the West Kootenay. Ten survey stations in this study are located within 15 kilometres of the Duncan Dam Reservoir, of which four are always impacted, four are occasionally impacted, and two are never impacted. There are hydrometric monitoring stations immediately downstream of the reservoir on Duncan River (station ID: 08NH118) and on the nearby Lardeau River at Marblehead (station ID: 08NH007). The natural hydrological regime of the area, as measured at monitoring station 08NH007, is superficially similar to most stations within the West Kootenay which are never impacted (ECCC 2018). Annual surveys of wetland characteristics typically took place from mid to late June. On average, the mean monthly discharge and water levels at both hydrometric stations are at their seasonal peak in June (ECCC 2018). Given that both regimes are experiencing peak levels at the time of the surveys and would therefore be comparable to one another, differences in the prevalence of open water are not simply due to one regime flooding at the time of surveys. The alternative to consider is that vegetation has been inhibited at impacted stations, resulting in higher percent open water as a product of less vegetation being present. Examining these two monitoring stations, the key differences between their hydrological regimes are longer periods of high discharge and water levels in the spring and a second sustained inundation in the winter at 08NH118, the station downstream of Duncan Dam and Reservoir (ECCC 2018). Campbell et al. (2016) observed that while some emergent species can survive a single growing season of sustained flooding, few could survive multiple, successive seasons. The regime downstream of Duncan Dam Reservoir is not necessarily uniform across impacted waterbodies in the West Kootenay nor is it necessarily uniform across years. If this hydrological regime is common across the impacted stations in the West Kootenay, however, this extended period of flooding may be resulting in low survival of vegetation.

An interesting finding was that stations in the West Kootenay which are never impacted have less emergent and tall vegetation than those which are occasionally impacted (Figure 4). In theory, the stations which are never impacted are experiencing the natural hydrological regime for that given location. Additionally, while emergent vegetation cover was similar between regions at stations which are never impacted, median cover of tall vegetation was considerably higher in the Columbia Wetlands at 60% compared to 11% in the West Kootenay. This suggests that while water management impacts may alter vegetation communities, there are other contributing factors occurring in the West Kootenay. One possible explanation for the regional differences may be that the never impacted stations in the West Kootenay include a broader range of wetland types than in the Columbia Wetlands. The Columbia Wetlands includes a range of wetlands intended to be representative of the region, but the Columbia Wetlands are the largest contiguous wetlands in North America. While the stations include a diverse range of the wetland habitat available, wetland connectivity and perhaps continuity are likely much higher in the Columbia Wetlands than in the West Kootenay (Figure 1). This could mean that wetlands in the West Kootenay incorporate a broader range of soil types, microclimates, and perhaps vegetation assemblages. “Wet meadow”, “sedge meadow”, or “shallow marsh” are wetland classifications typified by shallow water with grasses and sedges, as opposed to “emergent deep marsh”, which is typified by the prevalence of cattails and rushes (Millar 1976, NWWG 1997). Within the West Kootenay, median percent cover of grass and grass-like sedges is higher at stations above 600 m in elevation (8% below 600 m and 68% above). The median amount of open water is the same above and below 600 m (35%), unfortunately I cannot comment on water depth as it was not measured as part of this study. The increased cover of grasses and grass-like sedges is not necessarily indicative that there are different wetland types present above 600 m in the West Kootenay, but it does suggest a shift in vegetation communities or a diverse collection of wetland types are being surveyed.

## 1.5. Conclusions

Wetlands are often among the habitats most impacted by hydroelectric dams and water management projects through altered hydrological regimes, sedimentation, and inundation severity and frequency. Given that marsh birds are typified by their dependence on marsh habitat for at least a portion of their life history, this leaves them among groups that are especially vulnerable to these impacts. This study confirms previous research that vegetation and other wetland characteristics are important driving forces of secretive marsh bird presence and wetland use. It also provides evidence that in the West Kootenay secretive marsh birds do seem to be influenced by hydroelectric and water management projects, at least in part due to altered wetland characteristics. I suggest that this could be the result of impacted hydrological regimes representing an extreme of what vegetation can typically tolerate, such as sudden flooding resulting in extended periods of high water and/or high rates of flow. Wetlands in the West Kootenay which are always impacted by water management operations have more open water and less emergent vegetation, both of which make them less likely to be occupied by secretive marsh bird species. Wetlands which are either occasionally or never impacted by water management projects have more desirable characteristics for these species and are more likely to be occupied. Key restoration considerations to support secretive marsh bird species in the West Kootenay include: prioritizing low elevation wetlands for conservation and management, restoring local hydrological regimes, facilitating “hemi-marsh” conditions, and limiting woody vegetation encroachment.

# Chapter 2. Significance for Restoration

## 2.1. Future Directions

This study found that certain vegetation groups can be important driving forces of secretive marsh bird presence and wetland use, however, results suggested that there were other factors contributing to occupancy beyond those examined. Other fine-scale aspects of the vegetation community that may contribute to marsh bird occupancy could include invasive vegetation. Invasion by non-native species is a common symptom of anthropogenic impacts and can undermine ecosystem structure and functionality. Invasive vegetation of little ecological value can reduce wetland quality for marsh bird use, subsequently reducing their presence at affected wetlands. For example, American bittern and Virginia rail occupancy can be negatively associated with the abundance of reed canary grass (*Phalaris arundinacea,* Glisson et al. 2015). Invasive species like reed canary grass can alter the physical structure of the wetland by reducing the diversity and quality of plant communities (Spyreas et al. 2010), forming dense monotypic stands (Spyreas et al. 2010, Glisson et al. 2015), and/or rapidly producing thick layers of matted vegetation (Glisson et al. 2015). This can reduce the prevalence of stiff-stemmed species, which provide more suitable nesting material, (Glisson et al. 2015) or reduce access to or availability of food sources, such as invertebrates and seeds (Spyreas et al. 2010). I recommend future studies undertake detailed surveys of the wetlands in both the West Kootenay and Columbia Wetlands, specifically examining the presence or prevalence of invasive and/or exotic vegetation. The results of these surveys can then be used to focus restoration initiatives targeting invasive vegetation.

Assessing marsh bird occupancy and population density provides a solid foundation for studying and restoring for local populations, however, these measures do not necessarily reflect underlying population dynamics. Examining key population drivers, such as reproductive success and survival, will be a valuable next step toward improving our understanding of what successfully restored wetlands look like for these species. Without this knowledge, we may risk creating enticing environments where birds are ultimately less successful, inadvertently creating an “ecological trap” (Battin 2004, Anteau et al. 2012). Species have evolved to respond accordingly to cues which will optimize their biological fitness, such as many marsh bird species using cattail cover as a cue for selecting suitable nest sites. If an ecosystem has been altered, these cues may no longer be informative and may even mislead species to make decisions which ultimately diminish their biological fitness (Anteau et al. 2012), such as selecting nest areas which frequently flood. Given these secretive marsh bird species are already experiencing declines at a larger scale, practitioners and managers should avoid creating habitats which become ecological traps within the West Kootenay. In this study, three species had the highest population densities at stations which were occasionally affected by water management. We do not know, however, how the biological success of birds at these stations compares to that of individuals observed at stations which are never impacted. I suggest that additional studies are essential to better understand how wetland characteristics and the frequency of water management impacts affect reproductive success and survival.

In this study I found that while American bittern have been detected previously in the West Kootenay but in recent years they have been absent, detected only within the Columbia Wetlands. In 2010-2011 surveys, which were not considered in this study, American bittern were detected in the West Kootenay, specifically at stations in Creston Valley. American bittern populations were also reported in the Creston Valley Wildlife Management Area (CVWMA) and in the Columbia Wetlands during focused surveys in 2003 (Cooper and Beauchesne 2003). Cooper and Beauchesne (2003) found that most detections were within existing conservation properties, but there were numerous sites in both regions which had highly suitable wetlands and/or historical records of American bitterns where none were detected. Cooper and Beachesne's (2003) study included just one breeding season and it was a low-water year, therefore, it is possible more individuals could have been present if it were a typical season. In recent years, however, American bittern were detected exclusively in the Columbia Wetlands (Table 4). American bittern is still being detected in the CVWMA and surrounding area, however, there are no citizen-reported detections elsewhere within my West Kootenay study area in recent years (eBird 2012). Unfortunately, these findings may be confirming the continued decline of American bittern populations in Canada. Declines in American bittern populations have been reported across North America (Tozer 2013, Sauer et al. 2017). Things look more optimistic in the Columbia Wetlands. Cooper and Beauchesne (2003) noted that in their study bittern were only found in large (> several ha), shallow-water wetlands with large and/or dense patches of emergent vegetation, particularly cattails. I observed a similar preference in the Columbia Wetlands. Bitterns were detected at stations which generally had less than 40% open water and around 50% emergent vegetation cover, however, it should be noted that there are other stations with similar conditions where bitterns were not observed. American bittern in the Columbia Wetlands also tend to be detected in the same area year after year, in this case the wetlands just north of the community of Brisco and the Columbia National Wildlife Area. I recommend that future studies focused on American bittern populations and targeted conservation efforts, particularly in areas where they have been consistently observed, should be considered a priority.

## 2.2. Restoration

Hydroelectricity generation is frequently cited as an environmentally responsible method of electricity production. This is in large part due to the renewable nature of hydroelectricity, lack of fossil fuel consumption, and its limited production of greenhouse gas emissions compared to other fossil-fuel driven methods of power production (Spellman 2015, Siddiqui and Dincer 2017). While these benefits are tangible economically and environmentally, water management projects still have significant impacts on ecosystems. Ecosystems may suffer disrupted or altered hydrological regimes (Toller and Nemetz 1997, Sheer and Steel 2006, Thorley 2008, Utzig and Schmidt 2011, Spellman 2015), altered water chemistry and quality (Toller 1994, Utzig and Schmidt 2011), sediment movement and deposition (Toller 1994, Toller and Nemetz 1997, Utzig and Schmidt 2011, Spellman 2015) decreased primary productivity (Toller and Nemetz 1997, Utzig and Schmidt 2011), degraded aquatic habitat (Sheer and Steel 2006, Thorley 2008, Penfold 2012), reduced habitat connectivity (Sheer and Steel 2006), and altered local weather patterns (Penfold 2012), among others. Demand for electricity within British Columbia is only increasing and will likely continue to do so. While hydroelectric and other water management projects do offer environmental benefits over fossil fuel-generated power options, they do dramatically alter the landscape they are constructed in. Given substantial declines in many bird populations across Canada, and how these declines are exacerbated for migratory species, understanding how these projects affect ecosystems along the Pacific Flyway is critical. Within the Pacific Flyway, the Columbia Wetlands and the West Kootenay both provide important wetland habitat for countless species. The West Kootenay have been altered by numerous water management projects, and this study provides key insight regarding how secretive marsh birds, wetland vegetation communities, and the frequency of water management impacts are associated with one another. Using the findings of this study, the recommendations I make below can be implemented in currently affected areas and be incorporated into future project planning to support secretive marsh birds.

Secretive marsh birds will be best supported by both conserving pristine wetlands and restoring those wetlands which have been degraded or altered. Wetland conservation should be considered first priority as restoration is challenging and it often takes many years post-restoration for wetlands to approach reference conditions. Marsh birds do use restored or created wetlands, but even several years post-restoration they are often still present in lower numbers and diversity compared to natural wetlands (Dault 2001, Glisson et al. 2015). This may be tied to divergent vegetation communities (Dault 2001, Hapner et al. 2011) or the presence/prevalence of invasive vegetation (Glisson et al. 2015) in restored wetlands. Moreno-Mateos et al (2012) found that restored or created wetlands only recovered a portion of their biological structure (77% on average), even after considerable recovery time had elapsed. This loss of biological structure is in large part due to the slow (an average of 30 years) recovery of plant assemblages, which approached but still failed to reach reference conditions even 100 years post-restoration (Moreno-Mateos et al. 2012). Restoration ecology is a relatively young science and natural systems are often incredibly complex. The time required to reach reference conditions, and the extent to which this is even possible, are dependent on numerous factors including hydrologic setting, local climate, and wetland size (Moreno-Mateos et al. 2012). Despite the challenges and time required, restoration is still a worthy endeavor and successful results can increase available wetland area and marsh bird presence. Marsh birds, including secretive marsh bird species, will use and nest in restored and created wetlands (Hickman 1994, Dault 2001, Fletcher and Koford 2003, Hapner et al. 2011, Glisson et al. 2015), and diversity does appear to increase with increasing time post-restoration (Dault 2001, Hapner et al. 2011).

Considering the challenges facing their populations and of wetland restoration in general, I am recommending that secretive marsh bird species would be best supported by both conserving and restoring wetlands within the West Kootenay. My study highlights ideal wetland conditions as: being lower in elevation; having minimal water management impacts, open water, and woody vegetation; and featuring ample amounts of tall vegetation. I have two primary recommendations. First, prioritize lower elevation wetlands for conservation and restoration efforts. Secretive marsh birds can thrive at a variety of elevations, but my results suggest that they are more likely to occupy wetlands at lower elevations. Individuals were still detected at some higher elevation wetlands, but lower elevation wetlands were generally more likely to be occupied by American coot, pied-billed grebe, sora, or Virginia rail (Tables 8-11, Figures 5-8). Lower elevation aquatic habitat is also more likely to be affected or lost due to water management operations (Utzig and Schmidt 2011). The lower elevation wetlands, therefore, are both at a greater risk of being lost or altered and more likely to be occupied by secretive marsh birds. When establishing priorities, I recommend lower elevation wetlands be given precedence over those at higher elevations. My second recommendation is to experimentally test restoring the natural hydrological regime to wetlands which are always impacted by water management operations. My results suggest that the frequency of water management impacts may be influencing wetland vegetation communities (Figure 4) which may contribute to lower marsh bird occupancy and density in these wetlands (Figures 2 and 3). An altered hydrological regime is a fundamental aspect of water management operations and could be the primary stressor in these wetland ecosystems. I recommend designing a restoration experiment testing whether restoring the natural hydrological regime to an affected wetland could increase marsh bird presence. An experiment could be devised with controls and two restoration treatments: 1) the hydrological regime is restored to an entirely natural state, and 2) the regime is restored to a state where it would only occasionally be impacted. While secretive marsh birds prefer less impacted wetlands, they do utilize wetlands which are occasionally impacted (Figures 2 and 3). This suggests a promising compromise for areas where restoring ecological integrity in its entirety is not feasible. It is necessary to determine whether restoring the hydrological regime is effective in increasing marsh bird presence and, if it is, to what extent the hydrological regime should be restored for restoration to be effective.

If large-scale restoration is not necessary or feasible, I recommend undertaking small-scale restorative actions to improve the suitability of existing wetlands for secretive marsh birds. Four of the five species were more likely to occupy and/or be detected in the Columbia Wetlands, the region which tended to have high amounts of tall vegetation (Figure 3). Where vegetation is sparse or lacking key functional groups, perhaps post-restoration or following disturbance, practitioners should aim for “hemi-marsh” conditions through strategic planting. A “hemi-marsh” condition has been cited as ideal for many wetland species (Kaminski and Prince 1981, Murkin et al. 1982). This consists of a roughly 50:50 ratio of highly interspersed emergent vegetation and open water cover, though ratio preferences vary slightly between species. This corresponds closely with my results, where birds were more frequently detected at stations which had an average emergent vegetation cover between 40-61% with open water between 37-42% (Figures 2-4). Emergent vegetation should be diverse, but include a significant portion of tall, persistent species such as cattails, rushes, bulrushes, and sedges. As the most effective ratio of emergent vegetation to open water likely varies between species (Kaminski and Prince 1981, Murkin et al. 1982), I advise restoring wetlands to varying “hemi-marsh” ratios to accommodate species-specificity and increase overall landscape heterogeneity. Additionally, the probability of American coot, pied-billed grebe, sora, or Virginia rail occupying a wetland decreased with increasing woody vegetation cover (Tables 8-11, Figures 5-8). This finding is well supported in literature (Naugle et al. 1999, Darrah and Krementz 2009 and 2010, Bolenbaugh et al. 2011, Nielson 2016). Woody vegetation includes trees and shrubs, perennial plants whose structural tissues are hard and reinforced with lignin and cellulose. I recommend that initial restoration measures include the removal of woody vegetation around the wetland margins, particularly where it borders emergent vegetation. Finally, I recommend removing invasive vegetation as targeted initiative for specific, affected wetlands. For example, yellow flag iris (*Iris pseudacorus*), an aggressive and prolific invasive considered a “noxious weed” under the provincial *Weed Control Act* (RSBC 1996 c. 487), is present at the Mel Deanna 1 wetland (personal observation, May 2018). This wetland would be a prime candidate for an invasive removal project or community initiative.

# References


Anteau MJ, Shaffer TL, Sherfy MH, Sovada MA, Stucker JH, Wiltermuth MT (2012) Nest survival of piping plovers at a dynamic reservoir indicates an ecological trap for a threatened population. *Oecologia* 170: 1167-1179.

Battin, J (2004) When Good Animals Love Bad Habitats: Ecological Traps and the Conservation of Animal Populations. *Conservation Biology* 18:1482-1491.

Baschuk MS, Koper N, Wrubleski DA, Goldsborough G (2012) Effects of Water Depth, Cover and Food Resources on Habitat Use of Marsh Birds and Waterfowl in Boreal Wetlands of Manitoba, Canada. *Waterbirds* 35: 44-55.

BC Conservation Data Centre (BC CDC) (1994a) Species Summary: *Fulica americana*. BC Ministry of Environment. http://a100.gov.bc.ca/pub/eswp/ (accessed 7 March 2019).

BC Conservation Data Centre (BC CDC) (1994b) Species Summary: *Botaurus lentiginosus*. BC Ministry of Environment. http://a100.gov.bc.ca/pub/eswp/ (accessed 7 March 2019).

BC Conservation Data Centre (BC CDC) (1995a) Species Summary: *Podilymbus podiceps*. BC Ministry of Environment. http://a100.gov.bc.ca/pub/eswp/ (accessed 7 March 2019).

BC Conservation Data Centre (BC CDC) (1995b) Species Summary: *Rallus limicola*. BC Ministry of Environment. http://a100.gov.bc.ca/pub/eswp/ (accessed 7 March 2019).

BC Conservation Data Centre (BC CDC) (1996) Species Summary: *Porzana carolina*. BC Ministry of Environment. http://a100.gov.bc.ca/pub/eswp/ (accessed 7 March 2019).

Bent AC (1919) Life Histories of North American Diving Birds: Order Pygopodes. Dover Publications, Inc, New York, USA.

Bent AC (1926) Life Histories of North American Marsh Birds: Orders Odontoglossae, Herodiones and Paludicolae. Dover Publications, Inc, New York, New York.

Bird Studies Canada (BSC) (2010) The Prairie and Parkland Marsh Monitoring Program – Training kit and instructions for surveying marsh birds and their habitats. Bird Studies Canada, Saskatoon, Saskatchewan.

Bolenbaugh JR, Krementz DG, Lehnen SE (2011) Secretive Marsh Bird Species Co-Occurrences and Habitat Associations Across the Midwest USA. *Journal of Fish and Wildlife Management* 2: 49-60.

Blom CWPM, Voesenek LACJ (1996) Flooding: the survival strategies of plants. *Tree* 11: 290-295.

Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L (2001) Introduction to Distance Sampling: Estimating abundance of biological populations. Oxford University Press Inc, New York, New York.

Bunn SE, Arthington AH (2002) Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. *Environmental Management* 30: 492-507.

Campbell D, Keddy PA, Broussard M, McFalls-Smith TB (2016) Small Changes in Flooding Have Large Consequences: Experimental Data from Ten Wetland Plants. *Wetlands* 36: 457-466.

Columbia River Treaty, Canada-United States, 16 September 1964.

Cooper JM, Beauchesne SM (2003) Short-eared Owl and American Bittern Inventory in the Columbia Basin, 2003. Prepared for Fish and Wildlife Compensation Program: Columbia Basin, Nelson, British Columbia.

Conway CJ (2011) Standardized North American marsh bird monitoring protocol. *Waterbirds* 34: 319-334.

Conway CJ, Eddleman WR, Anderson SH (1994) Nesting Success and Survival of Virginia Rails and Soras. *Wilson Bulletin* 106: 466-473.

Conway CJ, Gibbs JP (2005) Effectiveness of call-broadcast surveys for monitoring marsh birds. *The Auk* 122: 26-35.

Conway CJ, Sulzman C (2007) Status and habitat use of the California black rail in the southwestern USA. *Wetlands* 27: 987-998.

Cornell Lab of Ornithology (n.d.) All About Birds [online database]. https://www.allaboutbirds.org (accessed 15 November 2018).

COSEWIC (2001) Canadian Species at Risk, May 2001. Committee on the Status of Endangered Wildlife in Canada.

Coupé R, Stewart AC, Wikeem BM (1991) Chapter 15: Engelmann Spruce – Subalpine Fir Zone. Pages 223-236 In: Meidinger D, Pojar J (editors) Ecosystems of British Columbia. BC Ministry of Forests, Victoria, British Columbia.

Creston Valley Wildlife Act (1996) RSBC c. 84.

Creston Valley Wildlife Management Area (CVWMA). n.d. A Little History. https://www.crestonwildlife.ca/about/history (accessed 19 June 2018).

Darrah AJ, Krementz DG (2009) Distribution and Habitat Use of King Rails in the Illinois and Upper Mississippi River Valleys. *Journal of Wildlife Management* 73: 1380-1386.

Darrah AJ, Krementz DG (2010) Occupancy and Habitat Use of the Least Bittern and Pied-billed Grebe in the Illinois and Upper Mississippi River Valleys. *Waterbirds* 33: 367-375.

Dault RE (2001) Long-term effects of wetland restoration on bird communities in the Prairie Pothole Region of northwestern Iowa. MSc Thesis, Iowa State University, Ames, Iowa.

Davidson NC (2014) How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research* 65: 934-941.

Demarchi DA (2011) The British Columbia Ecoregion Classification, Third Edition. Ecosystem Information Section, Ministry of Environment, Victoria, British Columbia.

Dénes FV, Silveira LF, Beissinger SR (2015) Estimating abundance of unmarked animal populations: accounting for imperfect detection and other sources of zero inflation. *Methods in Ecology and Evolution* 6: 543-556.

Drakou EG, Kallimanis AS, Sgardelis SP, Pantis JD (2008) Landscape structure and habitat composition in reservoirs, lakes, and rivers. *Lake and Reservoir Management* 24: 244-260.

eBird (2012) eBird: An online database of bird distribution and abundance [online database]. eBird, Ithaca, New York. Available: http://www.ebird.org. Accessed: 2 February 2019.

Ellis LA, Stump SD, Weddle DM (2009) Southwestern willow flycatcher population and habitat response to reservoir inundation. *Journal of Wildlife Management* 73: 946-954.

Environment and Climate Change Canada [ECCC] (2018) Historical Hydrometric Data [online database] Available: https://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html. Accessed: 20 January 2019

Fairbairn SE, Dinsmore JJ (2001) Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. *Wetlands* 21: 41-47.

Fletcher RJ Jr, Koford RR (2003) Changes in Breeding Bird Populations with Habitat Restoration in Northern Iowa. *American Midland Naturalist* 150: 83-94.

Forbes MRL, Barkhouse HP, Smith PC (1989) Nest-Site Selection by Pied-Billed Grebes *Podilymbus podiceps. Ornis Scandinavica* 20: 211-218.

Gibbs JP, Melvin SM (1993) Call-Response Surveys for Monitoring Breeding Waterbirds. *Journal of Wildlife Management* 57: 27-34.

Glisson WJ, Brady RS, Paulios AT, Jacobi SK, Larkin DJ (2015) Sensitivity of Secretive Marsh Birds to Vegetation Condition in Natural and Restored Wetlands in Wisconsin. *Journal of Wildlife Management* 79: 1101-1116.

Gorenzel WP, Ryder RA, Braun CE (1982) Reproduction and Nest Site Characteristics of American Coots at Different Altitudes in Colorado. *Condor* 84: 59-65.

Grill G, Lehner B, Lumsdon AE, MacDonald GK, Zarfl C, Liermann CR (2015) An index-based framework for assessing patterns and trends in river fragmentation and flow regulation by global dams at multiple scales. *Environmental Research Letters* 10: 1-15.

Hapner JA, Reinartz JA, Fredlund GG, Leithoff KG, Cutright NJ, Mueller WP (2011) Avian Succession in Small Created and Restored Wetlands. *Wetlands* 31: 1089-1102.

Harms TM, Dinsmore SJ (2012) Density and Abundance of Secretive Marsh Birds in Iowa. *Waterbirds* 35: 208-216.

Harms TM, Dinsmore SJ (2014) Influence of Season and Time of Day on Marsh Bird Detections. *Wilson Journal of Ornithology* 126: 30-38.

Hepp M, Ware L, van Oort H, Beauchesne SM, Cooper JM, Green DJ (2018) Postfledging survival and local recruitment of a riparian songbird in habitat influenced by reservoir operations. *Avian Conservation and Ecology* 13: 12.

Hickman S (1994) Improvement of habitat quality for nesting and migrating birds at the Des Plaines River Wetlands Demonstration Project. *Ecological Engineering* 3: 485-494.

Hines JE (2006) PRESENCE - Software to estimate patch occupancy and related parameters. United States Geological Survey – Patuxent Wildlife Research Center. Accessed from: http://www.mbr-pwrc.usgs.gov/software/presence.html.

Hirst SM (1991) Impacts of the operation of existing hydroelectric developments on fishery resources in British Columbia. Volume II. Inland fisheries. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2093.

Hope GD, Mitchell WR, Llyod DA, Erickson WR, Harper WL, Wikeem BM (1991a) Chapter 10: Interior Douglas-fir Zone. Pages 153-166 In: Meidinger D, Pojar J (eds) Ecosystems of British Columbia. BC Ministry of Forests, Victoria, British Columbia.

Hope GD, Mitchell WR, Llyod DA, Harper WL, Wikeem BM (1991b) Chapter 12: Montane Spruce Zone. Pages 183-194 In: Meidinger D, Pojar J (eds) Ecosystems of British Columbia. BC Ministry of Forests, Victoria, British Columbia.

Horak GJ. (1970) A Comparative Study of the Foods of the Sora and Virginia Rail. *The Wilson Bulletin* 82: 206-213.

Kaminski RM, Prince HH (1981) Dabbling Duck and Aquatic Macroinvertebrate Responses to Manipulated Wetland Habitat. *Journal of Wildlife Management* 45: 1-15.

Kellner M, van Oort H (2011) Whatshan Project Water Use Plan: Whatshan Wildlife Monitoring (year 5). Report WGSMON-3 prepared for BC Hydro, Southern Interior, Whatshan.

Ketcheson MV, Braumandl TF, Meidinger D, Utzig G, Demarchi DA, Wikeem BM (1991) Chapter 11: Interior Cedar – Hemlock Zone. Pages 167-181 In: Meidinger D, Pojar J (eds) Ecosystems of British Columbia. BC Ministry of Forests, Victoria, British Columbia.

Lehner B, Liermann CR, Revenga C, Vörösmarty C, Fekete B, Crouzet P, Döll P, Endejan M, Frenkan K, Magome J, Nilsson C, Robertson JC, Rödel R, Sindorf N, Wisser D (2011) High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Frontier in Ecology and the Environment* 9: 494-502.

Lor S, Malecki RA (2006) Breeding Ecology and Nesting Habitat Associations of Five Marsh Bird Species in Western New York. *Waterbirds* 29: 427-436.

Manley I, Krebs J (2011) Wildlife Impacts Due to BC Hydro Dams in the Columbia Basin. Prepared for Fish and Wildlife Compensation Program: Columbia Basin, Nelson, British Columbia.

Millar JB (1976) Wetland classification in western Canada. Canadian Wildlife Service Report Series Number 37.

Moreno-Mateos D, Power ME, Comín FA, Yockteng R (2012) Structural and Functional Loss in Restored Wetland Ecosystems*. PLoS Biology* 10: 1-8.

Murkin HR, Kaminski RM, Titman RD (1982) Responses by dabbling ducks and aquatic invertebrates to an experimentally manipulated cattail marsh. Canadian *Journal of Zoology* 60: 2324-2332.

National Wetlands Working Group (NWWP) (1997) The Canadian Wetland Classification System. 2nd edition. Edited by BG Warner and CDA Rubec. Wetlands Research Centre, University of Waterloo, Waterloo, Ontario.

Naugle DE, Higgins KF, Nusser SM (1999) Effects of woody vegetation on prairie wetland birds. *Canadian Field-Naturalist* 113: 487-492.

Nielson P (2016) Secretive marsh birds of urban wetlands in the Washington, DC Metropolitan Area. PhD dissertation, University of Maryland, College Park.

Nilsson C, Jansson R, Zinko U (1997) Long-Term Responses of River-Margin Vegetation to Water-Level Regulation. *Science* 276: 798-800.

Nilsson C, Reidy CA, Dynesius M, Revenga C (2005) Fragmentation and Flow Regulation of the World's Large River Systems. *Science* 308: 405-408.

North American Bird Conservation Initiative Canada (NABCIC) (2012) The State of Canada's Birds, 2012. Environment Canada, Ottawa, Ontario.

Pedology Consultants, Quadra Economic Consultants Ltd., Robinson Consulting & Associates Ltd., Glen Smith Wildlife Resource Consultant Ltd. (1983) Opportunities for Wildlife and Recreation Development in the Columbia River Wetlands. Prepared for Fish and Wildlife Branch, British Columbia Ministry of Environment, National Second Century Fund of British Columbia, Ducks Unlimited Canada, and Canadian Wildlife Service.

Penfold GE (2012) A review of the range of impacts and benefits of the Columbia River Treaty on basin communities, the region and the province. BC Ministry of Energy, Mines and Natural Gas, Victoria, British Columbia.

R Core Team (2018) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Accessed from: https://www.R-project.org/.

Reitan O, Thingstad PG (1999) Responses of birds to damming – a review of the influence of lakes, dams and reservoirs on bird ecology. *Ornis Norvegica* 22: 3-37.

Sauer JR, Niven DK, Hines JE, Ziolkowski DJ, Jr, Pardieck KL, Fallon JE, Link WA (2017) The North American Breeding Bird Survey, Results and Analysis 1966 - 2015. Version 2.07.2017 USGS Patuxent Wildlife Research Center, Laurel, Maryland.

Seabloom EW, van der Valk AG, Moloney KA (1998) The role of water depth and soil temperature in determining initial composition of prairie wetland coenoclines. *Plant Ecology* 138: 203-216.

Sheer MB, Steel EA (2006) Lost watersheds: Barriers, aquatic habitat connectivity, and salmon persistence in the Willamette and Lower Columbia River basins. Transactions of the American Fisheries Society 135: 1654-1669.

Siddiqui O, Dincer I (2017) Comparative assessment of the environmental impacts of nuclear, wind and hydro-electric power plants in Ontario: A life cycle assessment. *Journal of Cleaner Production* 164: 848-860.

Spellman FR (2015) Chapter 4: Hydropower. Pages 103-163 In: Environmental Impacts of Renewable Energy. CRC Press, Boca Raton, Florida.

Spyreas G, Wilm BW, Plocher AE, Ketzner DM, Matthews JW, Ellis JL, Heske EJ (2010) Biological consequences of invasion by reed canary grass (*Phalaris arundinacea*). *Biological Invasions* 12: 1253-1267.

Thomas L, Buckland ST, Rexstad EA, Laake JL, Strindberg S, Hedley SL, Bishop JRB, Marques TA, Burnham KP (2010) Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47: 5-14.

Thorley JL (2008) Aquatic habitat losses and gains due to BC Hydro dams in the Columbia basin. A Poisson Consulting Ltd. report prepared for Fish and Wildlife Compensation Program – Columbia Basin, Nelson, British Columbia.

Toller S (1994) Sustainability and hydro development in the Columbia River basin. MSc thesis, University of British Columbia, Vancouver, British Columbia.

Toller S, Nemetz PN (1997) Assessing the impact of hydro development: A case study of the Columbia River basin in British Columbia. *BC Studies* 114: 5-30.

Tozer DC (2013) The Great Lakes Marsh Monitoring Program 1995-2012: 18 years of surveying birds and frogs as indicators of ecosystem health. Bird Studies Canada, Saskatoon, Saskatchewan.

Tozer DC, Drake KL, Falconer CM (2016) Modelling detection probability to improve marsh bird surveys in southern Canada and the Great Lakes states. *Avian Conservation and* Ecology 11: 3.

Utzig G, Schmidt D (2011) Dam footprint impact summary - BC Hydro dams in the Columbia basin. Prepared for Fish and Wildlife Compensation Program: Columbia Basin, Nelson, British Columbia.

van Oort H, Green DJ, Hepp M, Cooper JM (2015) Do fluctuating water levels alter nest survivorship in reservoir shrubs? *The Condor* 117: 376-385.

Weed Control Act (1996) RSBC, c. 487.

# Appendix A.

*Table A 1. Survey station names and permanent attributes in the West Kootenay study region. Hydro Rank refers to how frequently stations are affected by hydroelectric or water management projects and are interpreted as follows: 1 = station is always impacted, 2 = station is occasionally impacted, 3 = station is never impacted.*

| Station Name | Latitude | Longitude | Elevation | Hydro Rank |
|---|---|---|---|---|
| Apex 1 | 49.41518 | -117.22080 | 933 | 3 |
| Apex 2 | 49.41265 | -117.21652 | 926 | 3 |
| Argenta 1 | 50.18706 | -116.93492 | 543 | 2 |
| Argenta 2 | 50.18539 | -116.92941 | 542 | 2 |
| Argenta 3 | 50.18295 | -116.92525 | 536 | 2 |
| Argenta 4 | 50.17926 | -116.92479 | 537 | 1 |
| Argenta 5 | 50.17487 | -116.92356 | 534 | 1 |
| Beaumont 1 | 49.18578 | -117.36435 | 722 | 3 |
| Beaumont 2 | 49.18452 | -117.37116 | 718 | 3 |
| Beaumont 3 | 49.18615 | -117.37067 | 716 | 3 |
| Beaver | 49.18476 | -117.38355 | 715 | 3 |
| Bird Ck | 49.45702 | -117.47195 | 516 | 1 |
| Blueberry 1 | 49.24758 | -117.97733 | 1309 | 3 |
| Blueberry 2 | 49.24416 | -117.97923 | 1303 | 3 |
| Boilard Pond | 49.04636 | -117.52959 | 936 | 3 |
| Bombi | 49.23795 | -117.53056 | 1181 | 3 |
| Bonanza | 50.09087 | -117.46666 | 532 | 3 |
| Castlegar Sewage | 49.33088 | -117.66145 | 432 | 3 |
| CC1a-1 | 49.13098 | -116.62908 | | 2 |
| CC1b-2 | 49.129324 | -116.61629 | | 2 |
| CC1c-3 | 49.137577 | -116.61866 | | 2 |
| CC2a-1 | 49.121502 | -116.62367 | | 3 |
| CC2a-2 | 49.125519 | -116.63256 | | 3 |
| CC2b-1 | 49.115575 | -116.62343 | | 3 |
| CC2b-2 | 49.118964 | -116.61153 | | 3 |
| CC3-1 | 49.102013 | -116.61621 | | 3 |
| CC3-2 | 49.10852 | -116.61594 | | 3 |
| Champion 1 | 49.18452 | -117.62168 | 1047 | 3 |
| Champion 2 | 49.18688 | -117.62640 | 1048 | 3 |
| Champion 3 | 49.18971 | -117.63385 | 1070 | 3 |
| Champion 4 | 49.19044 | -117.62463 | 1049 | 3 |
| Clearwater | 49.39569 | -117.20219 | 916 | 3 |
| Crawford Bay 1 | 49.66288 | -116.82806 | 540 | 1 |
| Crawford Bay 2 | 49.66638 | -116.82281 | 540 | 3 |
| Deception 1 | 50.32944 | -117.04311 | 820 | 3 |
| Deception 2 | 50.33273 | -117.04538 | 836 | 3 |
| DLNA-1 | 49.205942 | -116.60615 | | 3 |
| DLNA-2 | 49.214475 | -116.60757 | | 3 |
| DLNA-3 | 49.213387 | -116.62091 | | 3 |
| DLNA-4 | 49.202316 | -116.63015 | | 3 |
| Erie 1 | 49.19111 | -117.35381 | 712 | 3 |

| | | | | |
|---|---|---|---|---|
| Erie 2 | 49.1891 | -117.33477 | 712 | 3 |
| Harrop | 49.60588 | -117.03773 | 540 | 1 |
| Hidden Lk | 49.06533 | -116.55614 | 536 | 2 |
| Hope Ck | 50.45979 | -117.19621 | 693 | 3 |
| Hunter Siding 1 | 50.11773 | -117.52280 | 660 | 3 |
| Hunter Siding 2 | 50.11533 | -117.51654 | 655 | 3 |
| Kupi 1 | 49.07104 | -116.56154 | 534 | 2 |
| Kupi 2 | 49.07308 | -116.55064 | 537 | 2 |
| Lardeau | 50.17756 | -116.95975 | 537 | 1 |
| LL1-1 | 49.146602 | -116.62666 | | 2 |
| LL1-2 | 49.160357 | -116.61189 | | 2 |
| LL1-3 | 49.157889 | -116.63454 | | 2 |
| LL2-1 | 49.161326 | -116.63087 | | 2 |
| LL2-2 | 49.166047 | -116.61390 | | 2 |
| LL2-3 | 49.173972 | -116.61563 | | 2 |
| LL3-1 | 49.177380 | -116.62183 | | 2 |
| LL3-2 | 49.180501 | -116.63246 | | 2 |
| LL4-1 | 49.181899 | -116.61653 | | 2 |
| LL4-2 | 49.184632 | -116.62698 | | 2 |
| Meadow Ck 1 | 50.21984 | -116.97983 | 535 | 1 |
| Meadow Ck 2 | 50.22605 | -116.98389 | 545 | 2 |
| Mel Deanna 1 | 49.23637 | -117.64457 | 718 | 3 |
| Mel Deanna 2 | 49.23208 | -117.64730 | 722 | 3 |
| Mud Lk 1 | 49.24198 | -117.99957 | 1299 | 3 |
| Mud Lk 2 | 49.24421 | -117.99326 | 1298 | 3 |
| Nancy Greene N | 49.26104 | -117.93730 | 1261 | 3 |
| Oasis | 49.13601 | -117.74052 | 438 | 3 |
| Oxbow | 49.30974 | -117.64626 | 421 | 1 |
| Pass Ck | 49.41967 | -117.62353 | 662 | 3 |
| Pedro Ck | 49.59469 | -117.57803 | 508 | 3 |
| Rapid Ck | 50.42285 | -117.14564 | 658 | 3 |
| Rosebud Lk | 49.04985 | -117.26414 | 809 | 3 |
| Skincus | 49.05111 | -116.53397 | 536 | 3 |
| Tanal 1 | 49.02885 | -116.52284 | 535 | 3 |
| Tanal 2 | 49.03235 | -116.51877 | 537 | 3 |
| Waldie I | 49.33287 | -117.65301 | 429 | 1 |

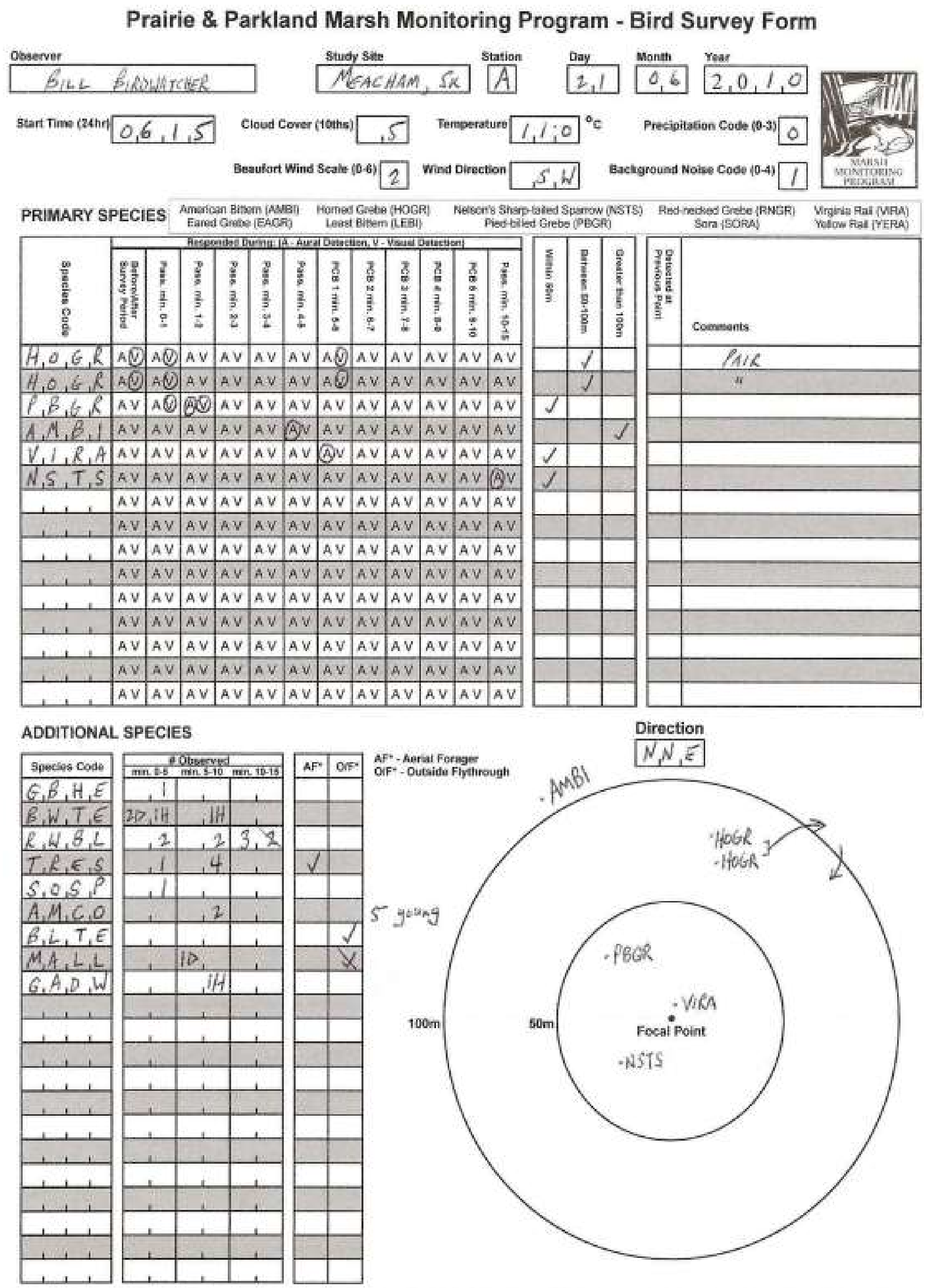
*Table A 2. Survey station names and permanent attributes in the Columbia Wetlands study region. Hydro Rank refers to how frequently stations are affected by hydroelectric or water management projects and are interpreted as follows: 1 = station is always impacted, 2 = station is occasionally impacted, and 3 = station is never impacted.*

| Station Name | Latitude | Longitude | Elevation | Hydro Rank |
|---|---|---|---|---|
| 9 Mile Slough | 51.19847 | -116.87725 | 788 | 3 |
| Athalmer | 50.51605 | -116.02212 | 800 | 3 |
| Beards Creek Rd N | 51.04951 | -116.59720 | 801 | 3 |
| Beards Creek Rd S | 51.03299 | -116.55724 | 792 | 3 |
| Beaver Lk 1 | 51.13290 | -116.74829 | 788 | 3 |
| Beaver Lk 2 | 51.12802 | -116.74682 | 791 | 3 |
| Birchlands | 51.15865 | -116.81362 | 785 | 3 |
| Bittern Lake | 50.97910 | -116.59967 | 1005 | 3 |
| Brisco xing | 50.82977 | -116.28352 | 796 | 3 |
| Brisco xing 2 | 50.82823 | -116.28915 | 794 | 3 |
| Brisco-Spilli 1 | 50.83211 | -116.29366 | 791 | 3 |
| Brisco-Spilli 2 | 50.83319 | -116.30087 | 793 | 3 |
| Brisco-Spilli 3 | 50.83746 | -116.30698 | 794 | 3 |
| Brisco-Spilli 4 | 50.84179 | -116.31397 | 794 | 3 |
| Brisco-Spilli 5 | 50.85126 | -116.32491 | 793 | 3 |
| Castledale North | 51.04049 | -116.57732 | 793 | 3 |
| Castledale Rest Area | 51.02691 | -116.53631 | 798 | 3 |
| Columbia Lk N | 50.30677 | -115.85259 | 815 | 3 |
| Edelweiss 1 | 51.32010 | -116.97759 | 784 | 3 |
| Edelweiss 2 | 51.32313 | -116.98531 | 786 | 3 |
| Fairmont | 50.34489 | -115.87254 | 806 | 3 |
| Fairmont 2 | 50.34953 | -115.87080 | 802 | 3 |
| Harrogate-Castledale 1 | 50.96533 | -116.44205 | 786 | 3 |
| Harrogate-Castledale 2 | 50.96528 | -116.45336 | 794 | 3 |
| Harrogate-Castledale 3 | 50.97353 | -116.46438 | 791 | 3 |
| Harrogate-Castledale 4 | 50.98212 | -116.47411 | 792 | 3 |
| Harrogate-Castledale 5 | 50.98709 | -116.47594 | 792 | 3 |
| Harrogate-Castledale 6 | 50.99172 | -116.48063 | 791 | 3 |
| Imler Rd | 51.09775 | -116.68826 | 793 | 3 |
| Lillian Lake | 50.50316 | -116.09798 | 939 | 3 |
| Loon Lake | 51.05515 | -116.80251 | 1235 | 3 |
| Luxor Station 1 | 50.76105 | -116.21243 | 760 | 3 |
| Luxor Station 2 | 50.75639 | -116.21552 | 794 | 3 |
| Luxor Station 3 | 50.77008 | -116.21576 | 794 | 3 |
| McKeeman's | 51.01866 | -116.51701 | 791 | 3 |
| McMurdo South | 51.13787 | -116.75592 | 786 | 3 |
| Mitten Lake North | 50.97710 | -116.58025 | 1015 | 3 |
| North Parson 1 | 51.13258 | -116.76147 | 781 | 3 |
| North Parson 2 | 51.13098 | -116.77771 | 790 | 3 |
| North Parson 3 | 51.13446 | -116.78103 | 786 | 3 |
| North Parson 4 | 51.14123 | -116.79841 | 788 | 3 |
| North Parson 5 | 51.14575 | -116.80497 | 795 | 3 |
| North Parson 7 | 51.15272 | -116.81291 | 790 | 3 |
| Old Barns Slough | 50.96389 | -116.42146 | 806 | 3 |

| | | | | |
|---|---|---|---|---|
| Parson - Beaver Lk 1 | 51.06898 | -116.66265 | 789 | 3 |
| Parson - Beaver Lk 2 | 51.07295 | -116.66894 | 787 | 3 |
| Parson - Beaver Lk 3 | 51.08289 | -116.67593 | 789 | 3 |
| Parson - Beaver Lk 4 | 51.08228 | -116.68871 | 790 | 3 |
| Parson - Beaver Lk 5 | 51.08756 | -116.70011 | 785 | 3 |
| Parson xing East | 51.07185 | -116.64146 | 788 | 3 |
| Parson xing West | 51.06161 | -116.64994 | 791 | 3 |
| Radium Mill Pond 1 | 50.62204 | -116.09402 | 801 | 3 |
| Radium Mill Pond 2 | 50.62389 | -116.10498 | 797 | 3 |
| Reflection Lake | 51.28328 | -116.94142 | 784 | 3 |
| Reflection Lake 2 | 51.28545 | -116.94985 | 784 | 3 |
| Salsbury Rd N | 50.99863 | -116.47415 | 794 | 3 |
| SE Lake Windemere | 50.41394 | -115.92677 | 802 | 3 |
| Spilli 1km S | 50.90178 | -116.36221 | 792 | 3 |
| Spilli xing East | 50.90453 | -116.36983 | 794 | 3 |
| Spilli xing West | 50.89764 | -116.38917 | 796 | 3 |
| Stewart's Slough | 50.89091 | -116.38342 | 797 | 3 |
| Val Davidson | 51.06456 | -116.65958 | 788 | 3 |
| Warner's Slough | 50.84223 | -116.32513 | 794 | 3 |
| Wilbur Lake | 51.00959 | -116.67711 | 1295 | 3 |
| Wilmer 1 | 50.55660 | -116.06824 | 800 | 3 |
| Wilmer 2 | 50.55863 | -116.06068 | 811 | 3 |
| Wilmer 3 | 50.56212 | -116.06171 | 814 | 3 |

# Appendix B.

Prairie and Parkland Marsh Monitoring Program Data - Bird Survey Form, reproduced with permission (BSC 2010).



**Prairie & Parkland Marsh Monitoring Program - Bird Survey Form**

Observer: BILL BIRDWATCHER | Study Site: MEACHAM, SK | Station: A | Day: 2,1 | Month: 0,6 | Year: 2,0,1,0

Start Time (24hr): 0,6,1,5 | Cloud Cover (10ths): ,5 | Temperature: 1,1;0 °C | Precipitation Code (0-3): 0

Beaufort Wind Scale (0-6): 2 | Wind Direction: ,S,W | Background Noise Code (0-4): 1

MARSH MONITORING PROGRAM

PRIMARY SPECIES: American Bittern (AMBI), Eared Grebe (EAGR), Horned Grebe (HOGR), Least Bittern (LEBI), Nelson's Sharp-tailed Sparrow (NSTS), Pied-billed Grebe (PBGR), Red-necked Grebe (RNGR), Sora (SORA), Virginia Rail (VIRA), Yellow Rail (YERA)

Responded During: (A - Aural Detection, V - Visual Detection)

| Species Code | Before/After Survey Period | Pass. min. 0-1 | Pass. min. 1-2 | Pass. min. 2-3 | Pass. min. 3-4 | Pass. min. 4-5 | PCB 1 min. 5-6 | PCB 2 min. 6-7 | PCB 3 min. 7-8 | PCB 4 min. 8-9 | PCB 5 min. 9-10 | Pass. min. 10-15 | Within 50m | Between 50-100m | Greater than 100m | Detected at Previous Point | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H,O,G,R | A(V) | A(V) | AV | AV | AV | AV | A(V) | AV | AV | AV | AV | AV | | ✓ | | | PAIR |
| H,O,G,R | (A)V | A(V) | AV | AV | AV | AV | A(V) | AV | AV | AV | AV | AV | | ✓ | | | " |
| P,B,G,R | AV | A(V) | (A)(V) | AV | AV | AV | AV | AV | AV | AV | AV | AV | ✓ | | | | |
| A,M,B,I | AV | AV | AV | AV | AV | (A)V | AV | AV | AV | AV | AV | AV | | | ✓ | | |
| V,I,R,A | AV | AV | AV | AV | AV | AV | (A)V | AV | AV | AV | AV | AV | ✓ | | | | |
| N,S,T,S | AV | AV | AV | AV | AV | AV | AV | AV | AV | AV | AV | (A)V | ✓ | | | | |

ADDITIONAL SPECIES

AF* - Aerial Forager
O/F* - Outside Flythrough

| Species Code | # Observed min. 0-5 | min. 5-10 | min. 10-15 | AF* | O/F* |
|---|---|---|---|---|---|
| G,B,H,E | 1 | | | | |
| B,W,T,E | 2D, 1H | 1H | | | |
| R,W,B,L | 2 | 2 | 3, 2 | | |
| T,R,E,S | 1 | 4 | | ✓ | |
| S,O,S,P | 1 | | | | |
| A,M,C,O | | 2 | | | |
| B,L,T,E | | | | | ✓ |
| M,A,L,L | | 1D | | | X |
| G,A,D,W | | 1H | | | |

5 young

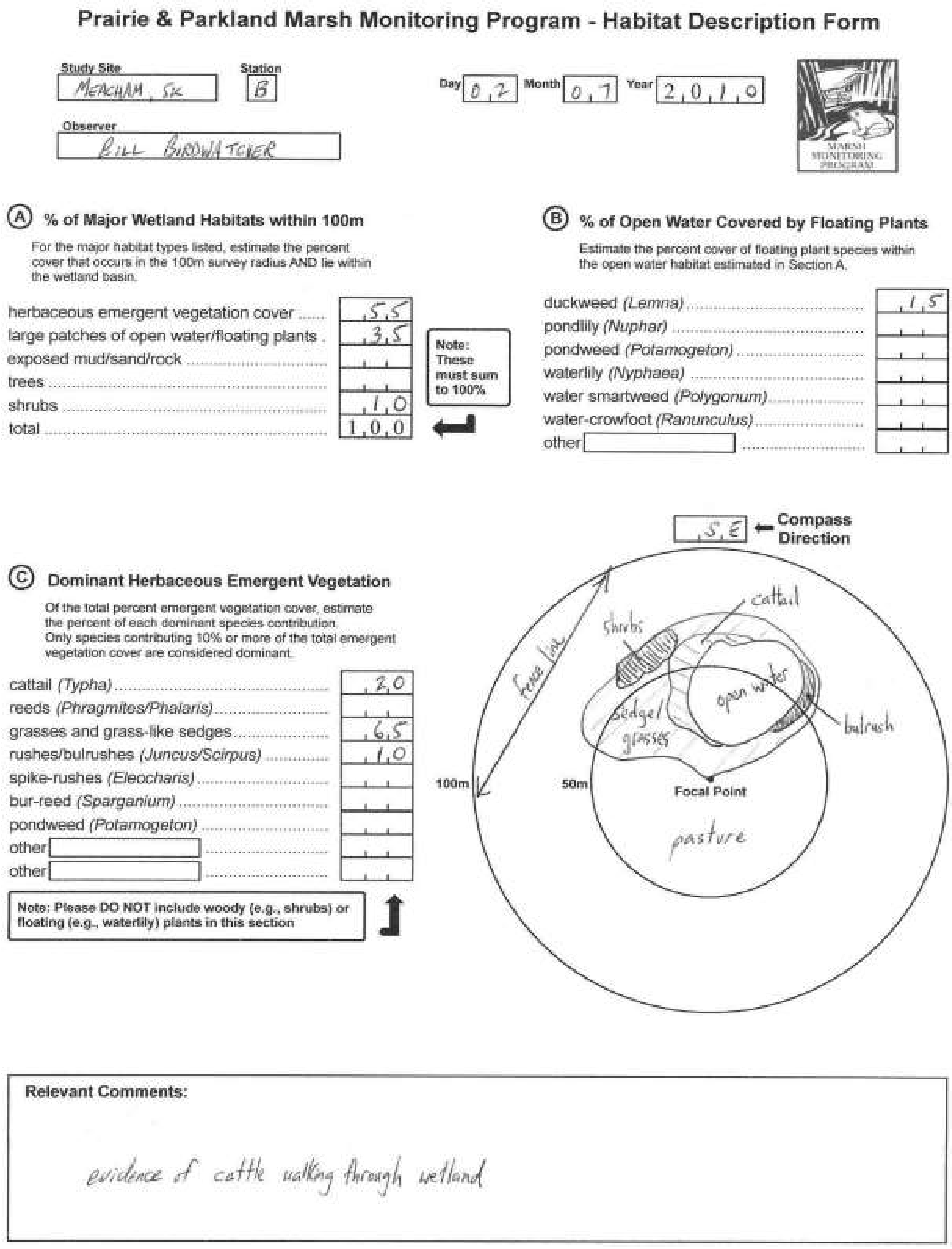
Direction: N,N,E



*Figure B 1. Survey form reproduced with permission from Prairie and Parkland Marsh Monitoring Program training manual (BSC 2010).*

# Appendix C.

Prairie and Parkland Marsh Monitoring Program Data – Habitat Description Form, reproduced with permission (BSC 2010).



**Prairie & Parkland Marsh Monitoring Program - Habitat Description Form**

Study Site: MEACHAM, SK
Station: B
Observer: BILL BIRDWATCHER
Day: 0 2 Month: 0 7 Year: 2 0 1 0

**(A) % of Major Wetland Habitats within 100m**

For the major habitat types listed, estimate the percent cover that occurs in the 100m survey radius AND lie within the wetland basin.

| | |
|---|---|
| herbaceous emergent vegetation cover | 55 |
| large patches of open water/floating plants | 35 |
| exposed mud/sand/rock | |
| trees | |
| shrubs | 10 |
| total | 100 |

Note: These must sum to 100%

**(B) % of Open Water Covered by Floating Plants**

Estimate the percent cover of floating plant species within the open water habitat estimated in Section A.

| | |
|---|---|
| duckweed *(Lemna)* | 15 |
| pondlily *(Nuphar)* | |
| pondweed *(Potamogeton)* | |
| waterlily *(Nyphaea)* | |
| water smartweed *(Polygonum)* | |
| water-crowfoot *(Ranunculus)* | |
| other | |

**(C) Dominant Herbaceous Emergent Vegetation**

Of the total percent emergent vegetation cover, estimate the percent of each dominant species contribution. Only species contributing 10% or more of the total emergent vegetation cover are considered dominant.

| | |
|---|---|
| cattail *(Typha)* | 20 |
| reeds *(Phragmites/Phalaris)* | |
| grasses and grass-like sedges | 65 |
| rushes/bulrushes *(Juncus/Scirpus)* | 10 |
| spike-rushes *(Eleocharis)* | |
| bur-reed *(Sparganium)* | |
| pondweed *(Potamogeton)* | |
| other | |
| other | |

Note: Please DO NOT include woody (e.g., shrubs) or floating (e.g., waterlily) plants in this section



**Relevant Comments:**

evidence of cattle walking through wetland

*Figure C 1. Habitat description form reproduced with permission from Prairie and Parkland Marsh Monitoring Program training manual (BSC 2010).*

# Appendix D.

*Table D 1 Full results of three sequential occupancy modelling stages for American coot.*

| Model | AIC | ΔAIC | Akaike Weight ($w_i$) | K |
|---|---|---|---|---|
| ***Detection (p)*** | | | | |
| Psi(year + hydro + region), p(day) | 785.24 | 0.00 | 0.67 | 6 |
| Psi(year + hydro + region), p(day + day$^2$) | 786.66 | 1.42 | 0.33 | 7 |
| Psi(year + hydro + region), p(.) | 802.07 | 16.83 | 0.00 | 5 |
| ***Occupancy (psi) - Region, Year, Hydro Ranking*** | | | | |
| Psi(region), p(day) | 781.46 | 0.00 | 0.37 | 4 |
| Psi(.), p(day) | 781.64 | 0.18 | 0.34 | 3 |
| Psi(hydro), p(day) | 783.32 | 1.86 | 0.15 | 4 |
| Psi(year), p(day) | 783.41 | 1.95 | 0.14 | 4 |
| ***Occupancy (psi) - Wetland Characteristics*** | | | | |
| Psi(region + water + woody + tall + elevation), p(day) | 675.70 | 0.00 | 0.93 | 8 |
| Psi(region + woody + elevation + emergent), p(day) | 681.76 | 6.06 | 0.05 | 7 |
| Psi(region + woody + elevation + tall), p(day) | 684.10 | 8.40 | 0.01 | 7 |
| Psi(region + woody + water + elevation), p(day) | 685.78 | 10.08 | 0.01 | 7 |
| Psi(woody + water + tall + elevation), p(day) | 691.58 | 15.88 | 0.00 | 7 |
| Psi(region + tall + water + elevation), p(day) | 692.64 | 16.94 | 0.00 | 7 |
| Psi(region + elevation + tall), p(day) | 695.32 | 19.62 | 0.00 | 6 |
| Psi(woody + elevation + tall), p(day) | 696.92 | 21.22 | 0.00 | 6 |
| Psi(region + elevation + emergent), p(day) | 699.38 | 23.68 | 0.00 | 6 |
| Psi(elevation + water + tall), p(day) | 700.46 | 24.76 | 0.00 | 6 |
| Psi(tall + elevation), p(day) | 702.52 | 26.82 | 0.00 | 5 |
| Psi(region + elevation + woody), p(day) | 703.42 | 27.72 | 0.00 | 6 |
| Psi(region + woody + water + tall), p(day) | 704.07 | 28.37 | 0.00 | 7 |
| Psi(woody + water + tall), p(day) | 705.33 | 29.63 | 0.00 | 6 |
| Psi(region + tall + woody), p(day) | 708.61 | 32.91 | 0.00 | 6 |
| Psi(tall + woody), p(day) | 708.73 | 33.03 | 0.00 | 5 |
| Psi(woody + elevation + emergent), p(day) | 715.63 | 39.93 | 0.00 | 6 |
| Psi(region + elevation + water), p(day) | 718.53 | 42.83 | 0.00 | 6 |
| Psi(woody + water + elevation), p(day) | 718.61 | 42.91 | 0.00 | 6 |
| Psi(emergent + elevation), p(day) | 722.04 | 46.34 | 0.00 | 5 |
| Psi(region + emergent + woody), p(day) | 723.73 | 48.03 | 0.00 | 6 |
| Psi(tall), p(day) | 726.30 | 50.60 | 0.00 | 4 |
| Psi(tall + water), p(day) | 726.90 | 51.20 | 0.00 | 5 |
| Psi(region + elevation), p(day) | 727.09 | 51.39 | 0.00 | 5 |
| Psi(region + tall), p(day) | 727.59 | 51.89 | 0.00 | 5 |
| Psi(region + tall + water), p(day) | 728.14 | 52.44 | 0.00 | 6 |

| | | | | |
|---|---|---|---|---|
| Psi(region + woody + water), p(day) | 729.10 | 53.40 | 0.00 | 6 |
| Psi(woody + elevation), p(day) | 734.28 | 58.58 | 0.00 | 5 |
| Psi(water + elevation), p(day) | 737.64 | 61.94 | 0.00 | 5 |
| Psi(emergent + woody), p(day) | 740.24 | 64.54 | 0.00 | 5 |
| Psi(region + woody), p(day) | 741.18 | 65.48 | 0.00 | 5 |
| Psi(woody + water), p(day) | 744.73 | 69.03 | 0.00 | 5 |
| Psi(elevation), p(day) | 746.27 | 70.57 | 0.00 | 4 |
| Psi(woody), p(day) | 754.40 | 78.70 | 0.00 | 4 |
| Psi(region + emergent), p(day) | 759.62 | 83.92 | 0.00 | 5 |
| Psi(emergent), p(day) | 761.62 | 85.92 | 0.00 | 4 |
| Psi(region + water), p(day) | 780.29 | 104.59 | 0.00 | 5 |
| Psi(water), p(day) | 780.37 | 104.67 | 0.00 | 4 |
| Psi(region), p(day) | 781.46 | 105.76 | 0.00 | 4 |
| Psi(.), p(day) | 781.64 | 105.94 | 0.00 | 3 |

*Table D 2 Full results of three sequential occupancy modelling stages for pied-billed grebe.*

| Model | AIC | ΔAIC | Akaike Weight ($w_i$) | K |
|---|---|---|---|---|
| ***Detection (p)*** | | | | |
| Psi(year + hydro + region), p(day + day$^2$) | 914.93 | 0.00 | 1.00 | 7 |
| Psi(year + hydro + region), p(.) | 927.36 | 12.43 | 0.00 | 5 |
| Psi(year + hydro + region), p(day) | 927.65 | 12.72 | 0.00 | 6 |
| ***Occupancy (psi) - Region, Year, Hydro Ranking*** | | | | |
| Psi(region + year), p(day + day$^2$) | 913.38 | 0.00 | 0.35 | 6 |
| Psi(region ), p(day + day$^2$) | 913.49 | 0.11 | 0.33 | 5 |
| Psi(year + hydro + region), p(day + day$^2$) | 914.93 | 1.55 | 0.16 | 7 |
| Psi(region + hydro), p(day + day$^2$) | 915.06 | 1.68 | 0.15 | 6 |
| Psi(hydro + year), p(day + day$^2$) | 974.03 | 60.65 | 0.00 | 6 |
| Psi(year), p(day + day$^2$) | 977.30 | 63.92 | 0.00 | 5 |
| Psi(hydro), p(day + day$^2$) | 986.03 | 72.65 | 0.00 | 5 |
| Psi(.),p(day + day$^2$) | 993.84 | 80.46 | 0.00 | 4 |
| ***Occupancy (psi) - Wetland Characteristics*** | | | | |
| Psi(region + year + woody + tall + elevation + water), p(day + day$^2$) | 820.61 | 0.00 | 0.85 | 10 |
| Psi(region + year + woody + tall + elevation), p(day + day$^2$)) | 824.14 | 3.53 | 0.15 | 9 |
| Psi(region + year + tall + elevation), p(day + day$^2$) | 833.50 | 12.89 | 0.00 | 8 |
| Psi(region + year + water + tall + elevation), p(day + day$^2$) | 834.16 | 13.55 | 0.00 | 9 |
| Psi(region + year + water + woody + tall), p(day + day$^2$) | 837.88 | 17.27 | 0.00 | 9 |
| Psi(region + year + woody + emergent + elevation), p(day + day$^2$) | 838.09 | 17.48 | 0.00 | 9 |
| Psi(region + year + water + woody + elevation), p(day + day$^2$) | 839.52 | 18.91 | 0.00 | 9 |
| Psi(region + year + woody + tall), p(day + day$^2$) | 841.34 | 20.73 | 0.00 | 8 |
| Psi(region + year + woody + elevation), p(day + day$^2$) | 851.12 | 30.51 | 0.00 | 8 |
| Psi(region + year + emergent + elevation), p(day + day$^2$) | 854.27 | 33.66 | 0.00 | 8 |
| Psi(region + year + tall), p(day + day$^2$) | 855.10 | 34.49 | 0.00 | 7 |
| Psi(region + year + water + tall), p(day + day$^2$) | 856.42 | 35.81 | 0.00 | 8 |
| Psi(region + year + water + elevation), p(day + day$^2$)) | 866.95 | 46.34 | 0.00 | 8 |
| Psi(region + year + elevation), p(day + day$^2$) | 870.41 | 49.80 | 0.00 | 7 |
| Psi(region + year + woody + emergent), p(day + day$^2$) | 870.69 | 50.08 | 0.00 | 8 |
| Psi(region + year + water + woody), p(day + day$^2$) | 873.22 | 52.61 | 0.00 | 8 |
| Psi(region + year + woody), p(day + day$^2$) | 883.30 | 62.69 | 0.00 | 7 |
| Psi(region + year + emergent), p(day + day$^2$) | 897.19 | 76.58 | 0.00 | 7 |
| Psi(tall), p(day + day$^2$) | 906.11 | 85.50 | 0.00 | 5 |

| | | | | |
|---|---|---|---|---|
| Psi(water + tall), p(day + $day^2$) | 907.49 | 86.88 | 0.00 | 6 |
| Psi(tall + elevation), p(day + $day^2$) | 907.75 | 87.14 | 0.00 | 6 |
| Psi(woody + tall), p(day + $day^2$) | 908.10 | 87.49 | 0.00 | 6 |
| Psi(water + tall + elevation), p(day + $day^2$) | 908.97 | 88.36 | 0.00 | 7 |
| Psi(water + woody + tall), p(day + $day^2$) | 909.41 | 88.80 | 0.00 | 7 |
| Psi(woody + tall + elevation), p(day + $day^2$) | 909.74 | 89.13 | 0.00 | 7 |
| Psi(water + woody + tall + elevation), p(day + $day^2$) | 910.95 | 90.34 | 0.00 | 8 |
| Psi(region + year + water), p(day + $day^2$) | 912.69 | 92.08 | 0.00 | 7 |
| Psi(region + year), p(day + $day^2$) | 913.38 | 92.77 | 0.00 | 6 |
| Psi(emergent + elevation), p(day + $day^2$) | 980.71 | 160.10 | 0.00 | 6 |
| Psi(woody + emergent + elevation), p(day + $day^2$) | 982.13 | 161.52 | 0.00 | 7 |
| Psi(water + woody + elevation), p(day + $day^2$) | 982.28 | 161.67 | 0.00 | 7 |
| Psi(water + elevation), p(day + $day^2$) | 983.64 | 163.03 | 0.00 | 6 |
| Psi(elevation), p(day + $day^2$) | 986.43 | 165.82 | 0.00 | 5 |
| Psi(woody + elevation), p(day + $day^2$) | 986.90 | 166.29 | 0.00 | 6 |
| Psi(woody + emergent), p(day + $day^2$) | 987.98 | 167.37 | 0.00 | 6 |
| Psi(emergent), p(day + $day^2$) | 988.43 | 167.82 | 0.00 | 5 |
| Psi(water + woody), p(day + $day^2$) | 988.87 | 168.26 | 0.00 | 6 |
| Psi(woody), p(day + $day^2$) | 991.96 | 171.35 | 0.00 | 5 |
| Psi(water), p(day + $day^2$) | 993.29 | 172.68 | 0.00 | 5 |
| Psi(.),p(day + $day^2$) | 993.84 | 173.23 | 0.00 | 4 |

*Table D 3 Full results of three sequential occupancy modelling stages for sora.*

| Model | AIC | ΔAIC | Akaike Weight ($w_i$) | K |
|---|---|---|---|---|
| ***Detection (p)*** | | | | |
| Psi(year + hydro + region), p(day + day$^2$) | 1178.51 | 0.00 | 0.47 | 7 |
| Psi(year + hydro + region), p(.) | 1179.01 | 0.50 | 0.37 | 5 |
| Psi(year + hydro + region), p(day) | 1180.64 | 2.13 | 0.16 | 6 |
| ***Occupancy (psi) - Region, Year, Hydro Ranking*** | | | | |
| Psi(region), p(day + day$^2$) | 1179.21 | 0.00 | 0.66 | 5 |
| Psi(region + year), p(day + day$^2$) | 1180.57 | 1.36 | 0.34 | 6 |
| Psi(year), p(day + day$^2$) | 1217.23 | 38.02 | 0.00 | 5 |
| Psi(.), p(day + day$^2$) | 1226.99 | 47.78 | 0.00 | 4 |
| Psi(hydro), p(day + day$^2$) | 1228.21 | 49.00 | 0.00 | 5 |
| ***Occupancy (psi) - Wetland Characteristics*** | | | | |
| Psi(region + water + woody + elevation), p(day + day$^2$) | 1095.26 | 0.00 | 0.49 | 8 |
| Psi(region + water + woody + tall + elevation), p(day + day$^2$) | 1096.41 | 1.15 | 0.28 | 9 |
| Psi(region + woody + emergent + elevation), p(day + day$^2$) | 1097.01 | 1.75 | 0.21 | 8 |
| Psi(region + emergent + elevation), p(day + day$^2$) | 1101.26 | 6.00 | 0.02 | 7 |
| Psi(region + water + tall + elevation), p(day + day$^2$) | 1112.74 | 17.48 | 0.00 | 8 |
| Psi(region + water + elevation), p(day + day$^2$) | 1116.98 | 21.72 | 0.00 | 7 |
| Psi(region + woody + tall + elevation), p(day + day$^2$) | 1123.69 | 28.43 | 0.00 | 8 |
| Psi(region + tall + elevation), p(day + day$^2$) | 1127.35 | 32.09 | 0.00 | 7 |
| Psi(region + water + woody + tall), p(day + day2) | 1128.06 | 32.80 | 0.00 | 8 |
| Psi(region + woody + elevation), p(day + day$^2$) | 1129.24 | 33.98 | 0.00 | 7 |
| Psi(region + elevation), p(day + day$^2$) | 1137.26 | 42.00 | 0.00 | 6 |
| Psi(region + woody + emergent), p(day + day$^2$) | 1137.60 | 42.34 | 0.00 | 7 |
| Psi(region + water + woody), p(day + day$^2$) | 1139.67 | 44.41 | 0.00 | 7 |
| Psi(region + woody + tall), p(day + day$^2$) | 1143.12 | 47.86 | 0.00 | 7 |
| Psi(region + water + tall), p(day + day$^2$) | 1143.40 | 48.14 | 0.00 | 7 |
| Psi(region + tall), p(day + day$^2$) | 1149.29 | 54.03 | 0.00 | 6 |
| Psi(region + emergent), p(day + day$^2$) | 1149.92 | 54.66 | 0.00 | 6 |
| Psi(water + woody + tall + elevation), p(day + day$^2$) | 1160.23 | 64.97 | 0.00 | 8 |
| Psi(water + tall + elevation), p(day + day$^2$) | 1160.29 | 65.03 | 0.00 | 7 |
| Psi(region + woody), p(day + day$^2$) | 1161.94 | 66.68 | 0.00 | 6 |
| Psi(tall + elevation), p(day + day$^2$) | 1169.82 | 74.56 | 0.00 | 6 |
| Psi(water + woody + tall), p(day + day$^2$) | 1170.10 | 74.84 | 0.00 | 7 |
| Psi(region + water), p(day + day$^2$) | 1170.31 | 75.05 | 0.00 | 6 |
| Psi(water + tall), p(day + day$^2$) | 1171.31 | 76.05 | 0.00 | 6 |
| Psi(woody + tall + elevation), p(day + day$^2$) | 1171.77 | 76.51 | 0.00 | 7 |
| Psi(tall), p(day + day$^2$) | 1176.02 | 80.76 | 0.00 | 5 |
| Psi(woody + tall), p(day + day$^2$) | 1177.42 | 82.16 | 0.00 | 6 |

| | | | | |
|---|---|---|---|---|
| Psi(region), p(day + $day^2$) | 1179.21 | 83.95 | 0.00 | 5 |
| Psi(water + woody + elevation), p(day + $day^2$) | 1185.77 | 90.51 | 0.00 | 7 |
| Psi(emergent + elevation), p(day + $day^2$) | 1186.16 | 90.90 | 0.00 | 6 |
| Psi(woody + emergent + elevation), p(day + $day^2$) | 1187.98 | 92.72 | 0.00 | 7 |
| Psi(water + elevation), p(day + $day^2$) | 1189.58 | 94.32 | 0.00 | 6 |
| Psi(elevation), p(day + $day^2$) | 1206.07 | 110.81 | 0.00 | 5 |
| Psi(woody + elevation), p(day + $day^2$) | 1206.72 | 111.46 | 0.00 | 6 |
| Psi(woody + emergent), p(day + $day^2$) | 1208.32 | 113.06 | 0.00 | 6 |
| Psi(water + woody), p(day + $day^2$) | 1208.80 | 113.54 | 0.00 | 6 |
| Psi(emergent), p(day + $day^2$) | 1208.96 | 113.70 | 0.00 | 5 |
| Psi(water), p(day + $day^2$) | 1218.34 | 123.08 | 0.00 | 5 |
| Psi(woody), p(day + $day^2$) | 1224.04 | 128.78 | 0.00 | 5 |
| Psi(.),p(day + $day^2$) | 1226.99 | 131.73 | 0.00 | 4 |

*Table D 4 Full results of three sequential occupancy modelling stages for Virginia rail.*

| Model | AIC | ΔAIC | Akaike Weight ($w_i$) | K |
|---|---|---|---|---|
| ***Detection (p)*** | | | | |
| Psi(year + hydro + region), p(day + day$^2$) | 924.27 | 0.00 | 0.50 | 7 |
| Psi(year + hydro + region), p(day) | 924.30 | 0.03 | 0.50 | 6 |
| Psi(year + hydro + region), p(.) | 939.29 | 15.02 | 0.00 | 5 |
| ***Occupancy (psi) - Region, Year, Hydro Ranking*** | | | | |
| Psi(region + hydro), p(day) | 922.36 | 0.00 | 0.84 | 5 |
| Psi(region), p(day) | 926.73 | 4.37 | 0.09 | 4 |
| Psi(hydro), p(day) | 929.12 | 6.76 | 0.03 | 4 |
| Psi(.), p(day) | 929.50 | 7.14 | 0.02 | 3 |
| Psi(year), p(day) | 930.29 | 7.93 | 0.02 | 4 |
| ***Occupancy (psi) - Wetland Characteristics*** | | | | |
| Psi(region + hydro + water + woody + tall + elevation), p(day) | 806.04 | 0.00 | 0.91 | 9 |
| Psi(region + hydro + water + tall + elevation), p(day) | 810.86 | 4.82 | 0.08 | 8 |
| Psi(region + hydro + water + woody + tall), p(day) | 816.97 | 10.93 | 0.00 | 8 |
| Psi(region + hydro + water + tall), p(day) | 819.76 | 13.72 | 0.00 | 7 |
| Psi(water + woody + tall + elevation), p(day) | 826.91 | 20.87 | 0.00 | 7 |
| Psi(region + hydro + water + woody + elevation), p(day) | 829.55 | 23.51 | 0.00 | 8 |
| Psi(region + hydro + woody + emergent + elevation), p(day) | 832.34 | 26.30 | 0.00 | 8 |
| Psi(region + hydro + emergent + elevation), p(day) | 833.58 | 27.54 | 0.00 | 7 |
| Psi(water + tall + elevation), p(day) | 834.66 | 28.62 | 0.00 | 6 |
| Psi(water + woody + tall), p(day) | 835.90 | 29.86 | 0.00 | 6 |
| Psi(region + hydro + tall + elevation), p(day) | 839.92 | 33.88 | 0.00 | 7 |
| Psi(region + hydro + woody + tall + elevation), p(day) | 840.77 | 34.73 | 0.00 | 8 |
| Psi(region + hydro + tall), p(day) | 845.02 | 38.98 | 0.00 | 6 |
| Psi(region + hydro + woody + tall), p(day) | 846.14 | 40.10 | 0.00 | 7 |
| Psi(water + tall), p(day) | 847.40 | 41.36 | 0.00 | 5 |
| Psi(water + woody + elevation), p(day) | 848.79 | 42.75 | 0.00 | 6 |
| Psi(emergent + elevation), p(day) | 849.87 | 43.83 | 0.00 | 5 |
| Psi(region + hydro + water + elevation), p(day) | 850.37 | 44.33 | 0.00 | 7 |
| Psi(woody + emergent + elevation), p(day) | 851.17 | 45.13 | 0.00 | 6 |
| Psi(water + elevation), p(day) | 864.95 | 58.91 | 0.00 | 5 |
| Psi(region + hydro + woody + emergent), p(day) | 868.24 | 62.20 | 0.00 | 7 |
| Psi(woody + emergent), p(day) | 869.72 | 63.68 | 0.00 | 5 |
| Psi(region + hydro + water + woody), p(day) | 870.67 | 64.63 | 0.00 | 7 |
| Psi(tall + elevation), p(day) | 871.63 | 65.59 | 0.00 | 5 |
| Psi(woody + tall + elevation), p(day) | 871.76 | 65.72 | 0.00 | 6 |
| Psi(water + woody), p(day) | 871.85 | 65.81 | 0.00 | 5 |

| | | | | |
|---|---|---|---|---|
| Psi(region + hydro + emergent), p(day) | 871.86 | 65.82 | 0.00 | 6 |
| Psi(emergent), p(day) | 872.57 | 66.53 | 0.00 | 4 |
| Psi(woody + tall), p(day) | 874.73 | 68.69 | 0.00 | 5 |
| Psi(region + hydro + woody + elevation), p(day) | 876.26 | 70.22 | 0.00 | 7 |
| Psi(tall), p(day) | 876.89 | 70.85 | 0.00 | 4 |
| Psi(region + hydro + elevation), p(day) | 885.62 | 79.58 | 0.00 | 6 |
| Psi(region + hydro + water), p(day) | 895.43 | 89.39 | 0.00 | 6 |
| Psi(water), p(day) | 897.85 | 91.81 | 0.00 | 4 |
| Psi(woody + elevation), p(day) | 908.64 | 102.60 | 0.00 | 5 |
| Psi(region + hydro + woody), p(day) | 910.83 | 104.79 | 0.00 | 6 |
| Psi(elevation), p(day) | 912.18 | 106.14 | 0.00 | 4 |
| Psi(woody), p(day) | 919.99 | 113.95 | 0.00 | 4 |
| Psi(region + hydro), p(day) | 922.36 | 116.32 | 0.00 | 5 |
| Psi(.), p(day) | 929.50 | 123.46 | 0.00 | 3 |