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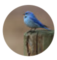

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Abundance Estimates for Marsh Bird Species in the Columbia Wetlands, British Columbia, Canada

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Abstract.—The Columbia Wetlands are one of the largest contiguous wetland complexes in western North America. Current population estimates are necessary for designation of priority conservation areas and for reliable assessment of population status for species of conservation concern. This multi-year study (2016–2019) was designed to estimate abundances of focal and secondary marsh birds using standardized call-broadcast protocols and distance sampling methods. Abundances of focal species varied by year, and mean population estimates indicated the most abundant secretive marsh birds were Sora (*Porzana carolina*; 4605 birds), followed by American Coot (*Fulica americana*; 2358 birds), Virginia Rail (*Rallus limicola*; 2124 birds), and Pied-billed Grebe (*Podilymbus podiceps*; 1657 birds). Most abundant secondary species were Marsh Wren (*Cistothorus palustris*; 6328 birds), Red-winged Blackbird (*Agelaius phoeniceus*; 5422 birds), Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*; 884 birds), and Wilson's Snipe (*Gallinago delicata*; 445 birds). Habitat covariates for detection functions varied by species, tended to include woody vegetation, tall vegetation, and open water; supporting previous studies proposing that a 'hemi-marsh' state is an important habitat condition for many marsh bird species. The Columbia Wetlands provide important wetland habitat and these estimates underscore the need for effective management for the conservation of British Columbia's avifauna. *Received 20 Aug 2021, accepted 3 Jan 2023.*

Key words.— abundance estimates, call-broadcast, Columbia wetlands, conservation, Distance sampling, focal species, habitat covariates, hemi-marsh, marsh birds

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Wetlands are valuable ecosystems that provide multiple ecosystem services, including carbon sequestration, flood damping, pollutant filtering, and water storage (Mitsch *et al.* 2015). Many wetlands also provide important habitats for numerous bird species that use them for nesting and brood-rearing (McKinney *at al.* 2011). Worldwide, nearly 57% of global wetlands have been lost since 1900 AD, and up to 87% of natural wetlands have been lost since 1700 AD (Davidson 2014). These losses are primarily driven by damming and water diversions, climate change, and agricultural practices such as filling, diking, and draining (Brinson and Malvárez 2002). Wetland loss is one potential contributor to the population declines documented in many wetland-dependant bird species (Conway *et al.* 1994; Niemuth and Solberg 2003; Peterjohn and Sauer 1997). Developing current and reliable population estimates for birds using regionally important wetlands is therefore a high priority for wetland conservation.

Wetland and riparian specialists such as marsh birds may be particularly vulnerable to changes in wetland availability and quality, and marsh birds can serve as excellent indicators of the biological condition or integrity of wetlands (Crewe and Timmermans 2005; DeLuca 2004). However, many marsh bird species are secretive, vocalize quietly or infrequently, are cryptically coloured, and often occupy densely vegetated and inaccessible areas making them challenging to accurately survey (Conway 2011). While passive surveys of marsh birds may provide some indication of population change, they significantly underestimate abundances, and broadcast techniques are recommended to provide more accurate estimates (Conway and Gibbs 2005; Gibbs and Melvin 1993). Marsh bird species distributions, population estimates, and trends generated using these combined methods are also unestablished for many wetland ecosystems.

The Columbia wetlands in the southern interior of British Columbia, Canada, are considered one of the largest contiguous wetlands in western North America (Hammond 2007), and their ecological significance is recognized internationally (Ramsar Convention on Wetlands 1971; Hammond 2007). The diverse habitats comprising the wetlands act as refugia for numerous waterbird species that use the area during breeding and migration (Darvill 2020; Hammond 2007; Rooney *et al.* 2013). Recent multi-year spring and fall bird surveys documented at least 163 bird species using the Columbia wetlands (Darvill 2020), 14 of which are considered at-risk by the British Columbia Conservation Data Centre. The Columbia wetlands holds exceptional bird species diversity, with at least 237 bird species documented to occur in this habitat (Leighton 2006). While these bird surveys indicate the potential importance of the wetlands for numerous waterbird populations, few standardized surveys have been conducted to establish population estimates in the area (Kaiser *et al.* 1977).

Anthropogenic disturbances such as agricultural practices, increasing levels of non-motorised recreational use, and urban and rural development nearby the wetlands with high potential to negatively influence these avian communities further highlights the need for baseline population data. Local livestock grazing can negatively affect wetland ecosystems by altering the composition and structure of vegetation (Jones *et al.* 2011), nutrients, conductivity, and pH levels (Epele and Miserendina 2015), and promote invasive species introductions (Hobbs 2001), and trampling of riparian and emergent vegetation required by waterbirds for nest building material and food (Weller and Spatcher 1965, Jones *et al.* 2011). Several studies (Korschgen and Dahlgren 1992; Hockin *et al.* 1992; Korschgen *et al.* 1985; Liddle and Scorgie 1980; York 1994) have reported the negative consequences of recreational activities on waterbirds, such as reduced foraging and resting periods; increased flushing, flight times, and energy expenditure by birds reducing their overall energy intake; increased nest abandonment and egg loss; discouragement of late-nesting pairs from breeding; disruption of pair bonds and parent-offspring bonds; reduced use of feeding, resting and breeding sites. Assessing population-level repercussions of such uses of wetland habitat requires reliable population estimates.

Gathering reliable baseline population data for marsh birds using the Columbia wetlands, including which species are present, in what numbers, and general habitat associations can supply critical information to decision makers. Additionally, having an accurate baseline assessment is important to ensuring that species population losses are documented, timely conservation steps are taken, and the success or failure of management actions are measurable. The overall objective for this project was to derive population estimates for secretive marsh birds in the Columbia wetlands. Using data collected as the Columbia Wetlands Marsh Bird Monitoring Project (CWMBMP), we report on a four-year study aimed at collecting annual baseline data on marsh birds during the breeding season. We used distance sampling techniques to develop detection functions and then estimate total abundance of marsh birds using established habitat models.

Methods

Study area

The Columbia wetlands (50°51′37.31″N, 116°20′12.06″W) are situated along the Rocky Mountain Trench between the Rocky and Purcell mountain ranges in southeastern British Columbia, Canada. The wetlands cover nearly 26,000 hectares and are adjacent to approximately 180 km of the Columbia River; they occupy the floodplains from Canal Flats to Donald near the Kinbasket Reservoir (Pedology *et al.* 1983). Much of the Columbia wetlands fall within the provincial Columbia Wetlands Wildlife Management Area and the smaller federal Columbia National Wildlife Area. Additional wetland areas are privately owned, including First Nation Reserve Lands (BC Hydro 2014), conservation lands, and parcels within the Agricultural Land Reserve.

Study design

To generate population estimates of the Columbia wetlands complex, we conducted bird surveys at up to 65 individual stations per year from 2016–2019. Most stations were surveyed annually, however some were not surveyed each year due to logistical constraints (e.g., hard to access with kayak during high water, private land owner access permissions had changed). As such, the yearly number of survey stations ranged from 61 to 65 stations, except for the 2016 pilot year study when

37 stations were surveyed. Following Conway (2011), we conducted three surveys per station during peak breeding season each year when individuals were more likely to be vocal and responsive while establishing territories and seeking mates. Typically, surveys were completed between 04 May and 30 June, with the exception of one survey route completed on 01 July 2017 due to persistent poor weather conditions. To control for habitat variables that may influence bird detectability and/or abundance we paired bird surveys with habitat surveys.

Station site selection

The Columbia wetlands complex encompasses a mosaic of broad habitat types each of which may vary in its suitability to support marsh birds. To ensure our population estimates were representative of the majority of the wetland complex we aimed to establish survey stations at random points situated throughout the wetland. However, since much of the Columbia wetlands are inaccessible (there is little road access on the west side and private land covers much of the east side) we selected some station locations based on accessibility and landowner permissions (Fig. 1). While kayak-accessed stations were situated within paddling distance of safe boat launches and often closer together than road accessed locations, all survey stations were spaced in accordance with the Standardized North American Marsh Bird Monitoring Protocol (Conway 2011). Upon arriving at each station, we marked the location with a handheld GPS and noted specific landmarks to ensure survey areas were consistent within seasons and among years.

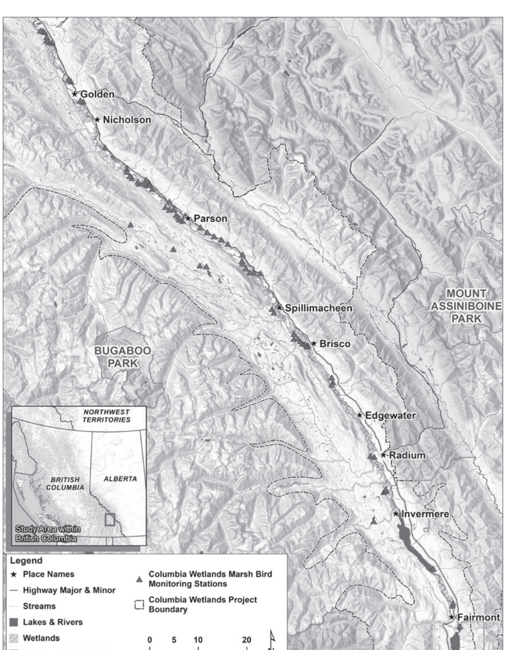

Figure 1. Locations for all point count stations of the Columbia Wetlands Marsh Bird Monitoring Project.

Bird surveys

We conducted single-observer bird surveys following the Prairie and Parkland Marsh Monitoring Program developed by Birds Canada (BSC 2010) and the Standardized North American Marsh Bird Monitoring Protocol by Conway (2011). Broadcast techniques are more effective in detecting secretive species compared to exclusively passive surveys (Conway and Gibbs 2005; Gibbs and Melvin 1993). Thus, during surveys we used a FoxPro Firestorm speaker to broadcast call sequences from a focal point at each survey station. Each survey was conducted in the morning by one primary observer per station, often accompanied by a volunteer who remained silent during the survey window. The surveys began no earlier than 30 minutes before sunrise and ended no later than 10:00 hr on each survey date (Conway 2011); we did not conduct evening surveys which differed from the Conway (2011) protocol. When an individual bird was heard, we used a laser rangefinder to estimate distance from observer. We then converted exact location distances from observers into distance bins (i.e., < 50 m, 50–100 m, > 100 m).

Adjusting to local conditions, survey start date and time of day deviated slightly from the Conway (2011) protocol. A few stations were visited less than three times during each breeding season when it did not make logistical sense (i.e., access difficulties), and survey start dates differed slightly across years (May 4–May 14). Surveys began when marsh birds were initially heard with frequency within the study area in a given year. Surveys were conducted only when weather conditions were favorable, for instance, no precipitation, minimal wind, good visibility. If weather conditions were unfavourable, or become poor partway through a survey route, the remaining surveys were postponed and usually conducted on an alternate day.

Our call-broadcast surveys focused on five focal marsh bird species: American Bittern (*Botaurus lentiginosus*), American Coot (*Fulica americana*), Pied-billed Grebe (*Podilymbus podiceps*), Sora (*Porzana carolina*), and Virginia Rail (*Rallus limicola*). In addition to focal species, we also passively surveyed 51 secondary species of interest including: Brewer's Blackbird (*Euphagus cyanocephalus*), Eared Grebe (*Podiceps nigricollis*), Marsh Wren (*Cistothorus palustris*), Red-necked Grebe (*Podiceps grisegena*), Red-winged Blackbird (*Agelaius phoeniceus*), Wilson's Snipe (*Gallinago delicata*), and Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*).

Vegetation surveys

Upon completion of all bird surveys in late-June or early July, we conducted vegetation surveys following Prairie and Parkland Marsh Monitoring Program protocol (BSC 2010). During each survey we classified the station as being in one of the four dominant habitat types described above and estimated the proportional amount of each land cover type within a 100-m radius of the centre of each survey station. For land cover, we first estimated the percent cover of major vegetation communities (i.e., herbaceous emergent vegetation, open water/floating vegetation, exposed mud/sand/rock, trees, and shrubs) and then the percent cover of the dominant vegetation types within the herbaceous emergent vegetation and open water/floating communities.

Statistical analyses

Distance sampling. We used the *Distance* package (Miller *et al.* 2019) in R Studio (Core Team 2020) to estimate the abundances of marsh birds observed during surveys. Distance sampling methods are widely used to estimate species density and abundance while correcting for imperfect detection (Buckland *et al.* 2001). This approach calculates a detection function by determining how habitat covariates and distance from observer affect the probability of detecting individuals. Each detection function can then be used to estimate the density of birds within the survey area (Buckland *et al.* 2001) and then extended to estimate abundances over the entire study area (Miller *et al.* 2019).

Distance sampling methods rely on the assumption that four key criteria are met to produce reliable abundance estimates (Buckland *et al.* 2001). First, objects of interest are distributed independently of survey points, which can be achieved by ensuring points are randomly distributed throughout available habitat. Second, all objects directly on the point (i.e., distance 0 m from the observer) are detected and objects are correctly identified. Each observer was expertly trained in both aural and visual identification of local marsh birds and individual birds near the observer were readily detected, therefore, we are confident in our detection certainty. Third, objects were detected at their original location (i.e., prior to any movement, particularly any that may be related to the observer). We significantly increased the probability of detecting secretive species at their initial locations by using call-broadcast surveys with conspecifics to elicit responses (Gibbs and Melvin 1993). Lastly, distances between the observer and object of interest must be measured accurately. Each observer was well-trained and we used a handheld rangefinder to ensure the recorded distances between observer and individual were accurate. We feel confident that the measures we have taken ensure that these key criteria have been met and our estimates are reliable.

Model selection

Following Buckland *et al.* (2001), we initially considered models with half-normal, hazard-rate, and uniform key function detection-distance relationships. We used Akaike's Information Criterion (AIC) to rank models and examined models with ΔAIC values of less than 2 more closely (Akaike 1973). Models with half-normal key functions outperformed those using other key functions and were therefore used to estimate species abundance in subsequent models. A minimum sample size of 60–80 detections is recommended to produce reliable abundance estimates (Buckland *et al.* 2001). In our study, we detected fewer than 60 individuals of Virginia Rail, American Coot, American Bittern, Brewer's Blackbird, Eared Grebe, Red-necked Grebe, Wilson's Snipe, and Yellow-headed Blackbird in some or all years. To account for this, we pooled detections across years to produce a global detection function before stratifying estimates by study year.

Once a key function was selected, we incorporated additional covariates into more complex models to increase the accuracy of our abundance estimates. As the effects of vegetation and time of season on detectability may vary among species, we included both temporal and vegetation covariates. We included "Visit" (i.e., visit 1, 2, or 3) as a temporal covariate to account for variation throughout the breeding period. We included the proportional cover of different vegetation types to account for the influence of habitat. If habitat variables were highly correlated ($r \geq 0.70$) we only considered one in the model.

For species that were detected more than 60 times in each of three or more study years we ran a full suite of models that included individual and additive effects of year, and percent cover of open water/floating vegetation, woody vegetation (trees and shrubs), emergent vegetation (all species), and tall vegetation (i.e., cattails, *Typha* spp.; and rushes, *Scirpus/Juncus* spp., specifically). For species with fewer than 60 detections in a year, we considered an abbreviated set of models that only considered single covariates. In most instances the model with the lowest AIC value or within 2 AIC was selected; however, in a few instances the model with the lowest AIC value produced estimates with high coefficients of variation. In these instances, the next best model with lower coefficients of variation was selected. We used the final selected model and stratified detections by year to produce annual abundance estimates.

Abundance estimates

Following station site selection we checked for any habitat-related biases by calculating the proportion of sites situated in each major habitat type relative to the proportional availability of the habitat. To improve accuracy of our total abundance estimates and eliminate biases caused by over- or under-sampling "good" marsh bird habitat types relative to their proportional areas, we calculated the proportion of habitat types surveyed in relation to the true proportional area of those habitats in the entire wetland complex estimated using LiDAR (EcoLogic Consultants, unpublished; Table 1). Since our survey locations were within 5% of the true availability of habitat calculated using LiDAR, we were confident in our ability to extrapolate our abundance estimates. For our total population estimates, we assumed the number of marsh birds occupying upland forest or anthropogenic habitat was negligible.

Results

From 2016–2019 we conducted between 88 and 177 marsh bird surveys across the Columbia wetlands (Tables 2 and 3). The best supported models (ΔAIC < 2) for both

Table 1. Overview of the area and proportion of different habitat types and frequency at which each habitat type was surveyed in the Columbia Wetlands, British Columbia.

Dominant habitat	Area (ha)	Proportion of total area (%)	Number of Surveys	Proportion of surveys (%)
Marsh	7,806	47	34	52
Open Water	3,337	20	10	15
Shoreline/Floodplain	3,719	23	15	23
Swamp	1,607	10	6	9
Total	16,469	100	65	100

focal and secondary species contained the covariates "water", "woody", and "tall" most often (Tables 4 and 5). Among the top models (ΔAIC = 0), the co-variate "year" was most frequently selected for focal species (Table 4); however, "water" and "woody" were similarly selected for secondary species (Table 5).

Detections

For the focal species, Sora ($\bar{x}$ = 158 detections/year) had the highest number of detections per year followed by Pied-billed Grebe ($\bar{x}$ = 149), American Coot ($\bar{x}$ = 92), Virginia Rail ($\bar{x}$ = 35), and American Bittern ($n < 10$; Table 2). The few detections of American Bittern were all from five stations within the same general area. Among the secondary species, Red-winged Blackbird ($\bar{x}$ = 302 detections/year) had the highest number of detections followed by Marsh Wren ($\bar{x}$ = 177), Yellow-headed Blackbird ($\bar{x}$ = 80 birds), Wilson's Snipe ($\bar{x}$ = 48), and Red-necked Grebe ($\bar{x}$ = 22). Across study years, both Brewer's Blackbird and Eared Grebe had fewer than ten observations in a single season (Table 3).

Table 2. Abundance estimates and summary table for focal marsh bird species. Abundance estimates are calculated within the entirety of the Columbia wetlands, based on 16,469 ha of available habitat. Survey effort reflects the total number of surveys conducted over a study season across all study stations.

Species	Year	Survey effort	Number observed	Abundance estimate	CV (%)	95% CI	
Sora	2016	88	152	7,080	19	4,861	10,313
	2017	159	126	1,973	24	1,246	3,125
	2018	177	162	3,598	19	2,484	5,211
	2019	172	190	5,770	18	4,060	8,200
Virginia Rail[1]	2016	88	11	975	32	513	1,852
	2017	159	39	2,387	33	1,252	4,550
	2018	177	36	1,926	30	1,070	3,467
	2019	172	54	3,206	29	1,807	5,688
Pied-billed Grebe	2016	88	109	1,984	23	1,262	3,120
	2017	159	127	1,409	23	893	2,225
	2018	177	108	1,762	22	1,156	2,685
	2019	172	85	1,471	26	885	2,443
American Coot	2016	88	108	4,562	41	2,057	10,119
	2017	159	35	548	52	207	1,453
	2018	177	91	3,316	50	1,290	8,524
	2019	172	134	1,007	46	418	2,428
American Bittern	2016	88	1	—	—	—	—
	2017	159	7	—	—	—	—
	2018	177	10	—	—	—	—
	2019	172	3	—	—	—	—

Abbreviated model suite run.

Table 3. Abundance estimates and summary table for secondary marsh bird species. Abundance estimates are calculated within the entirety of the Columbia wetlands, based on 16,469 ha of available marsh habitat. Survey effort reflects the total number of surveys conducted over a study season across all study stations.

Species	Year	Survey effort	Number observed	Abundance estimate	CV (%)	95% CI	
Brewer's Blackbird	2016	88	9	—	—	—	—
	2017	159	0	—	—	—	—
	2018	177	0	—	—	—	—
	2019	172	0	—	—	—	—
Eared Grebe	2016	88	6	—	—	—	—
	2017	159	0	—	—	—	—
	2018	177	6	—	—	—	—
	2019	172	4	—	—	—	—
Marsh Wren	2016	88	130	4,125	24	2,559	6,651
	2017	159	211	7,369	21	4,890	11,103
	2018	177	175	6,067	23	3,878	9,490
	2019	172	192	7,752	20	5,211	11,534
Red-necked Grebe[1]	2016	88	12	234	68	68	810
	2017	159	11	69	69	20	238
	2018	177	24	210	56	74	597
	2019	172	39	415	56	147	1,167
Red-winged Blackbird	2016	88	180	5,272	14	3,973	6,997
	2017	159	306	5,337	14	4,078	6,984
	2018	177	339	5,246	14	3,973	6,927
	2019	172	382	5,834	12	4,572	7,443
Wilson's Snipe[1]	2016	88	28	183	20	122	275
	2017	159	25	92	56	33	258
	2018	177	62	726	35	371	1,420
	2019	172	77	779	31	430	1,411
Yellow-headed Blackbird[1]	2016	88	54	1,108	33	576	2,133
	2017	159	58	586	33	309	1,114
	2018	177	96	894	27	530	1,507
	2019	172	112	949	25	583	1,545

Abbreviated model suite run.

Population Estimates

Using abundances calculated by our top models for each species and extrapolating to the area of entire wetland complex (16,469 ha), we generated population estimates for breeding focal and secondary species. Of the focal species, Sora was the most abundant ($\bar{x}$ = 4605 birds/year) with relatively low uncertainty (Table 2). Sora was followed by American Coot ($\bar{x}$ = 2358 birds/year), Virginia Rail ($\bar{x}$ = 2124 birds/year), and Pied-billed Grebe ($\bar{x}$ = 1657 birds/year), with American Coot estimates generating the most uncertainty (Table 2). The most abundant secondary species (Table 3) was Marsh Wren ($\bar{x}$ = 6328 birds), followed by Red-winged Blackbird ($\bar{x}$ = 5422 birds), Yellow-headed Blackbird ($\bar{x}$ = 884 birds), Wilson's Snipe ($\bar{x}$ = 445 birds), and Red-necked Grebe ($\bar{x}$ = 232 birds). Red-winged Blackbird estimates consistently had the least uncertainty [smallest coefficient of variation (CV)], whereas Red-necked Grebe had the greatest (Table 3). Populations of American Bittern, Brewer's Blackbird, or Eared Grebe were not estimated, since the few observations would generate inflated or unreliable estimates even when pooling across study years. Abundance estimates calculated for study years with fewer than 60 detections of a given species generally had higher CVs and should be interpreted with caution. In terms of evaluating the fit of the models and the

Table 4. Summary of best supported (ΔAIC < 2) models for focal species by year. All models used the "Half-normal" detection function. Average detectability ($\hat{P}_\alpha$) and its associated standard error ($\hat{P}_\alpha$se) are included for reference and model comparison. Covariates refer to year of study as a factor and relative percent cover of open water/floating vegetation ("water"), woody vegetation (trees and shrubs; "woody"), emergent vegetation (i.e., all species, "herb"), and tall vegetation [i.e., cattails (*Typha* spp.), and rushes (*Scirpus/Juncus* spp.) specifically; "tall"].

Species	Formula	$\hat{P}_\alpha$	$\hat{P}_\alpha$se	ΔAIC
Sora	~water + tall + year	0.14	0.01	0.00
	~water + tall + woody + year	0.14	0.01	0.32
Virginia rail[1]	~herb	0.06	0.01	0.00
	~1 (intercept only)	0.04	0.61	0.53
	~water	0.06	0.01	1.03
Pied-billed grebe	~water + tall + year	0.26	0.02	0.00
	~water + tall + woody + year	0.26	0.02	0.55
American coot	~herb + woody + year	0.17	0.02	0.00
	~water + woody + year	0.17	0.02	0.69
	~woody + year	0.17	0.02	1.45

soundness of the resulting estimates, we considered all available detection functions, and we chose the one best supported by the data.

DISCUSSION

Abundance of marsh birds and conservation thresholds

While marsh bird populations around the world are facing significant population declines, the Columbia Wetlands provide refuge for multiple breeding marsh birds with ample and relatively ecologically intact breeding habitat. Using call-broadcast sequence surveys combined with distance sampling methods we estimate the Columbia wetlands provide breeding habitat for over 24,000 marsh birds (10,744 focal and 13,312 secondary species) each year. This estimate includes the five focal marsh bird species as well as the five secondary species that were found in highest abundance. Several additional marsh bird species are pres-

Table 5. Summary of best supported (ΔAIC < 2) models for secondary species by year. A less supported (ΔAIC > 2) model was included for Wilson's snipe, as this was the final model selected. All models used the "Half-normal" detection function. Average detectability ($\hat{P}_\alpha$) and its associated standard error ($\hat{P}_\alpha$se) are included for reference and model comparison. Covariates refer to year of study as a factor and relative percent cover of open water/floating vegetation ("water"), woody vegetation (trees and shrubs; "woody"), emergent vegetation (i.e., all species, "herb"), and tall vegetation [i.e., cattails (*Typha* spp.), and rushes (*Scirpus/Juncus* spp.) specifically; "tall"].

Species	Formula	$\hat{P}_\alpha$	$\hat{P}_\alpha$se	ΔAIC
Marsh Wren	~water + tall + woody + year	0.11	0.01	0.00
	~water + tall + year	0.11	0.01	1.69
Red-necked Grebe[1]	~woody	0.35	0.08	0.00
Red-winged Blackbird	~water + tall + woody + visit	0.21	0.01	0.00
	~water + tall + visit	0.22	0.01	0.28
	~water + tall + woody	0.22	0.01	0.32
	~tall + woody + visit	0.22	0.01	0.66
	~water + tall	0.22	0.01	1.05
	~tall + woody	0.22	0.01	1.34
Wilson's Snipe[1]	~year	0.36	0.08	0.00
	~water	0.37	0.06	2.21
Yellow-headed Blackbird[1]	~water	0.36	0.04	0.00

Abbreviated model suite run.

ent in this region and are unaccounted for in this study [e.g., Wood Duck (*Aix sponsa*), Great Blue Heron (*Ardea Herodias)*, Osprey (*Pandion haliaetus*), etc.]. There is significant inter-annual variation in marsh bird abundance in the Columbia Wetlands. Potential drivers may include climatic and water level fluctuations correlating to differences in the amount of available food, breeding habitat (emergent and floating vegetation), and cover from predators. Differences in the timing, location, and the amount of human activities may also have an effect on the abundance of breeding marsh birds.

An unanticipated result of this study was the identification (largely aural) of a relatively high abundance of both Sora and Pied-billed Grebe breeding in the wetlands, likely owing to their secretive and elusive nature. The resultant abundance estimates for Pied-billed Grebe may indicate that the Columbia Wetlands qualify for inclusion into the 'Key Biodiversity Area' (KBA) program, an initiative that works to identify, monitor and protect the world's most important biodiverse habitats (IUCN 2016).

Habitat relationships

Within the Columbia Wetlands, the habitat variables most frequently highlighted within our detection models were percent cover of vegetation and open water/floating vegetation. Previous studies have found negative associations between woody vegetation and some marsh bird species (Bolenbaugh *et al.* 2011, Darrah and Krementz 2010, Darrah and Krementz 2009, Naugle *et al.* 1999), possibly due to an increased presence of predators (Darrah and Krementz 2010, Naugle *et al.* 1999). Our strong association of woody vegetation with marsh bird presence is mainly owing to the shrubs on the levees that line all the river channels in the Columbia wetlands, not from an abundance of taller trees that predators tend to perch on. Smaller mammals (nest predators) may be using the shrubs to some extent, but this has not been investigated. Emergent vegetation has strong ecological relevance as a source of food, cover, and/or nesting material, and is frequently correlated with marsh bird presence (Baschuk *et al.* 2012, Bolenbaugh *et al.* 2011, Darrah and Krementz 2009, Fairbairn and Dinsmore 2001, Forbes *et al.* 1989, Lor and Malecki 2006). Dead stems of species like cattails and rushes may be particularly valuable to marsh birds given their persistence over-winter, providing early nesting material and cover in the spring (Gorenzel *et al.* 1982, Forbes *et al.* 1989, Lor and Malecki 2006). Relationships between marsh birds and open water or water depth, however, tend to be more species-dependent (Baschuk *et al.* 2012, Bolenbaugh *et al.* 2011, Lor and Malecki 2006).

Studies frequently note a "hemi-marsh" condition, where wetlands exhibit an even ratio of well-interspersed emergent vegetation and open water, as being ideal for many marsh bird species (Kaminski and Prince 1981, Lor and Malecki 2006, Murkin *et al.* 1982). The ideal ratio varies among species, for example approximately 50:50 for Pied-billed Grebes compared to > 70:30 for Sora and Virginia Rail (Lor and Malecki 2006). This 'hemi-marsh' concept been used globally for the management of wetlands for waterfowl and other birds (Smith *et al.* 2004). Greater species richness and usually higher waterbird density in hemi-marsh wetlands are generally identified in these areas, an observation attributed to more plentiful food, as well as the visual isolation that is provided between breeding pairs (Smith *et al.* 2004). While we did not examine interspersion specifically, we did find that both open water and tall vegetation were consistently important for detecting marsh birds. We also noted that marsh birds were not distributed equally across survey stations within the Columbia wetlands. Areas containing specific emergent plant species (i.e., cattails, *Typha spp.*; and rushes, *Scirpus/Juncus spp.*, specifically) with open water patches frequently had greater abundances and diversity of marsh bird species.

Recommendations for future studies

Before conservation initiatives and management strategies can be developed and implemented, it must first be determined what species are present, in what quantity, and what habitat areas are the most important to target for conservation efforts. The call-broadcast technique appeared effective for eliciting responses from all five focal species, and Sora and Pied-billed Grebe in particular. However, detections decreased significantly for all species as the day progressed, and we therefore suggest that surveys cease by 08:30 hr, rather than 10:00 hr. Additionally, only morning surveys were conducted for this project, yet the standardized protocol allows for both morning and evening surveys. We recommend that, where it is logistically possible, both morning and evening surveys be implemented in future monitoring programs. Certain broadcast species are detected more frequently during morning (Pied-billed Grebe) while detections are significantly higher for others (American Bittern, Sora, Virginia Rail) during the evening (Tozer *et al.* 2017). During one of the few surveys where American Bittern were detected, they were seen, but did not respond to calls. Evening surveys may help increase the detection frequency of bitterns, although monitoring during the evening can also pose logistical challenges (e.g., kayaking in the dark). While the call-broadcast technique can be effective, it is important to recognize that few, if any, survey methods are perfect. Another challenge can involve placement of survey stations. While spacing survey stations can help prevent double counting, some species may roam or their calls may carry over greater distances. This can introduce challenges in defining sufficient spacing between stations when surveying a range of species. Ultimately, the survey technique and study design used was an effective way to estimate marsh bird species populations in the Columbia wetlands, and we recommended that this approach be expanded to other regions looking to monitor marsh bird species and their habitats.

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