Columbia River Project Water Use Plan

ARROW LAKES RESERVOIR OPERATIONS MANAGEMENT PLAN

Reference: CLBMON-40

Arrow Lakes Reservoir: Arrow Lakes Reservoir Shorebird and Waterbird Monitoring Program

Study Period: 10 Year Final Report, 2008-2017

Hemmera Envirochem Inc.
18th Floor, 4730 Kingsway
Burnaby, BC V5H 0C6
T: 604.669.0424
F: 604.669.0430

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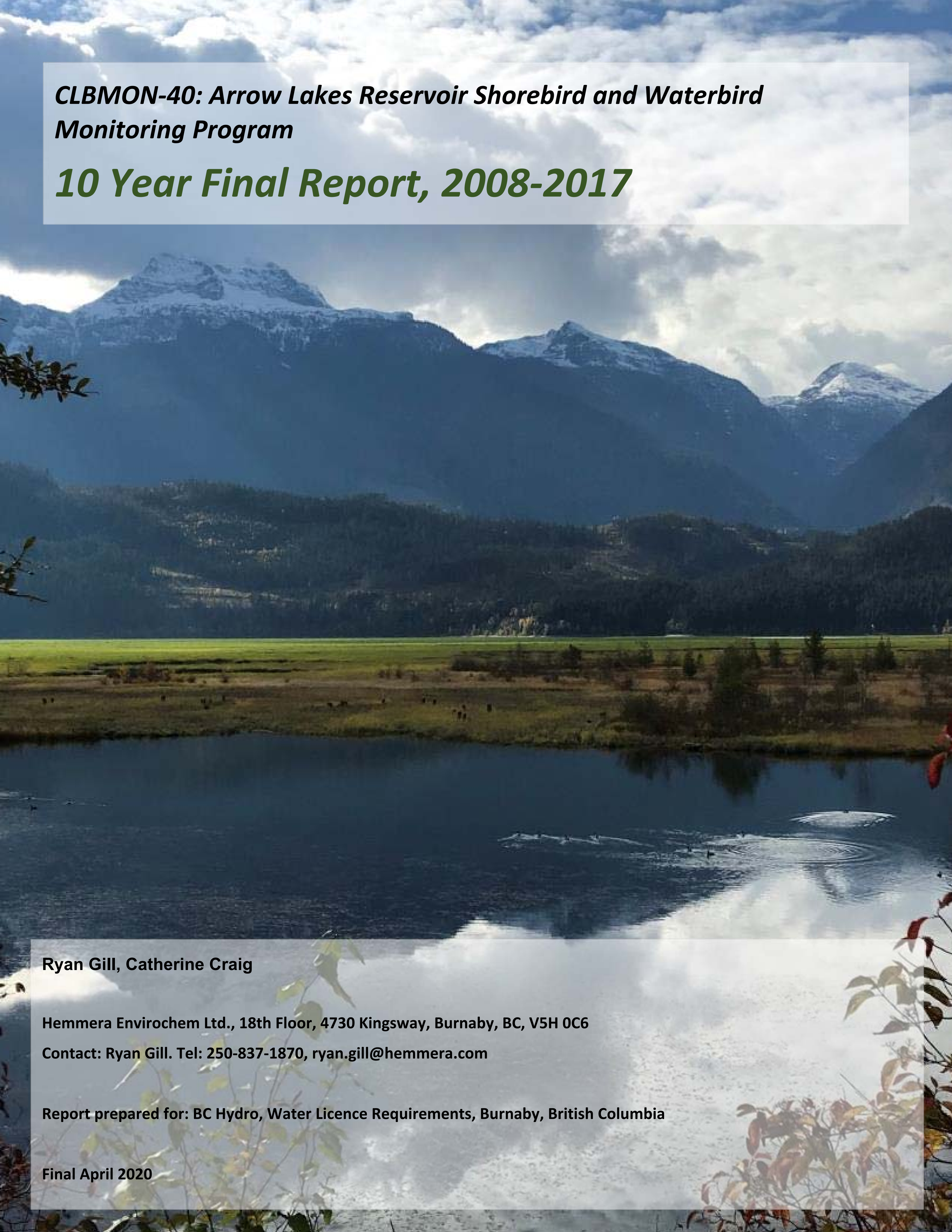

CLBMON-40: Arrow Lakes Reservoir Shorebird and Waterbird Monitoring Program

10 Year Final Report, 2008-2017

Ryan Gill, Catherine Craig

Hemmera Envirochem Ltd., 18th Floor, 4730 Kingsway, Burnaby, BC, V5H 0C6

Contact: Ryan Gill. Tel: 250-837-1870, ryan.gill@hemmera.com

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Cover photo: Montana Bay at low reservoir levels during fall migration. Photo: Ryan Gill.

EXECUTIVE SUMMARY

CLBMON-40 was a 10-year project designed to study the impacts of reservoir operations in Arrow Lakes Reservoir on waterbirds (waterfowl, loons, grebes, shorebirds, and four species of raptors associated with the drawdown zone). Field studies were conducted annually from 2008-2017 in Revelstoke Reach. Several survey methods (land-based counts, aerial surveys, brood surveys, habitat assessments, nest monitoring, boat-based counts) were implemented to answer the Management Questions (MQ) posed by BC Hydro. Sufficient data were collected to adequately address the Management Questions.

Usage of the drawdown zone by waterbirds was well-pronounced during the spring and fall migrations. The spring migration period was relatively short and peaked in mid-April, whereas the fall migration lasted several months and generally peaked in late October. Wetland features within the drawdown zone were disproportionately important habitats for migrant waterfowl. Cartier Bay was the most important wetland overall with a slightly higher proportion of diving ducks than Airport Marsh, which, with its extensive submergent vegetation, was favoured by dabbling ducks. Reservoir operations influenced wetland habitat during the fall migration, but not during the spring migration. During the fall migration, reservoir operations did not measurably influence the abundance of waterfowl in Revelstoke Reach, but did affect their distribution within the study area. Relatively few shorebirds stopped in RR during migration even when suitable habitat (exposed mud) is present. The effect of the reservoir on abundance and diversity of shorebirds is difficult to discern from broader ecological effects, but there was some tendency for a greater diversity of shorebirds at lower reservoir levels.

Within and among drawdown zone wetlands, habitat use by migrant waterfowl was determined mainly by water depth, with dabbling ducks and Canada Goose using shallower waters, and diving ducks using deeper waters. Distribution of waterfowl within wetlands changed when reservoir levels interacted with certain drawdown zone habitats. Dabbling duck density in wetlands decreased as water depth from inundation increased, and these birds moved to terrestrial habitats after they became flooded. There were four species of aquatic macrophyte that were widespread, and consistently associated with duck usage. Shorebirds were less frequently detected at high reservoir levels, with Spotted Sandpipers being the most common species, particularly at these high reservoir levels.

Waterfowl productivity varied annually, and more broods were observed in years when reservoir levels were relatively low during late spring/early summer. Ground-nesting ducks were more likely to have nests flooded during years with high reservoir levels or with rapid filling in late spring; the ground-nesting Canada Goose was usually able to produce young as this species nested before rising waters flooded their nest habitat. Canada Goose accounted for the majority of waterfowl broods observed. Tree-nesting duck species, although few, would not have experienced nest-flooding. Downie Marsh was disproportionately important for brood-rearing, and the Airport Marsh had importance as a waterfowl nesting area.

Bald Eagle had high nesting success (77%) regardless of reservoir operations. Up to 7 active nests were found annually in Revelstoke Reach from 2008 through 2015; 13 active nests were found annually from 2016 to 2017 when the study area was expanded to include Beaton Arm. Osprey were more numerous but had lower nesting success (45%), which was affected by June rainfall. Up to 12 active nests were found annually through 2015 and up to 20 were found annually from 2016 to 2017 when the study area was expanded to include Beaton Arm. More nests of both species were located on the west shore of Revelstoke Reach but nests on the east shore had higher numbers of young fledged.

During the spring migration, Short-eared Owl (SARA-listed as “Special Concern”) and Northern Harrier were observed annually in Revelstoke Reach, but nesting was infrequent. Both species forage and nest a relatively low-elevation grassland habitat that floods relatively early in the summer. Five Short-eared Owl nests were found in two of the 10 years of study and all failed due to nest flooding. The brood from one of the “failed nests” was rescued shortly before the nest would have flooded and young were raised in an animal care facility and then released near Creston. All other flooded Short-eared Owl nests contained clutches of eggs, not nestlings. Of the three Northern Harrier nests found, one was abandoned (2014), one was flooded, and one was successful (both in 2016). The successful harrier nest was positioned relatively high in the drawdown zone for this species, and the young fledged just prior to nest flooding. The risk of nest flooding for these species is considerable because rising waters flood all of their nesting and foraging habitat in most years.

In addition to presenting a direct threat to nesting success of Short-eared Owl and Northern Harrier, reservoir operations might also indirectly affect the likelihood of these species nesting in a given year, via the direct limitation that reservoir operations must have on their primary food source – meadow vole (*Microtus pennsylvanicus*). Short-eared Owl and Northern Harrier both nest opportunistically in response to unpredictable vole population cycles. It was hypothesized that reservoir operations regulate vole population cycles; in spring vole populations are reduced following years with high summer reservoir levels, making the drawdown zone habitat unattractive for nesting. Conversely, an extended period for exponential growth of the vole population, afforded by low reservoir elevations, predicts high vole abundance in the spring following years when summer reservoir levels didn’t inundate their habitat. Because reservoir operations are not highly autocorrelated from one year to the next, the presence of a dense vole population does not predict safe nesting and poses a high risk for ground-nesting avian vole predators.

Implementation of the soft constraint of maintaining reservoir levels below 438.4 m ASL from early August to late October, or the addition of REV 5 had no effect on waterbird habitat.

No physical works projects were constructed to enhance habitat for waterbirds during the study, although two projects were completed that protected important waterbird wetlands from degradation by erosion and draining. Possible projects could include creation of low elevation wetlands for migrant waterbirds, high elevation wetlands that are protected from flooding for nesting waterbirds, and mounded islands or floating artificial islands for ground-nesting waterfowl and shorebirds. Any physical works should take into consideration impacts to other wildlife species that may be affected and should be designed to avoid creation of ecological traps. Revegetation projects implemented during the study had no effect on waterbird abundance, productivity, or habitat.

In conclusion, reservoir operations had minor to no effect on migrant waterbird abundance, annual waterbird habitat quality, or tree-nesting raptor breeding success. Reservoir operations had a strong effect on migrant waterbird distribution, and ground-nesting waterfowl and raptor breeding success. Options for minimizing negative effects on breeding success through changes to reservoir operations and improvements to waterbird habitat through physical works are available.

Table 1-1: Status of objectives, management questions, and hypotheses

Management Question	Summary of Key Monitoring Results
MQ-1 What is the seasonal and annual variation in the abundance and spatial distribution of waterbirds within Revelstoke Reach during migration?	• This MQ was addressed for spring and fall waterfowl migrations, and for the fall shorebird migration, using a relatively large 10 year dataset. • The waterfowl migrations were highly pronounced in spring and fall, and this seasonal abundance effect overwhelmed other drivers of abundance (e.g., water levels). • Spatially, waterfowl preferentially selected wetlands and Cartier Bay and Airport Marsh were the two most important wetlands during migration. • In fall, waterfowl used the Revelstoke Reach wetlands as stop-over or staging habitat and were present for an extended period of time. The spring migration was more contracted. • The fall shorebird migration was well-pronounced temporally but was never observed to involve many shorebirds. Shorebirds generally moved rapidly through the study area in small groups. • The number and diversity of shorebirds varied considerably among years.
MQ-2	• This MQ was removed from the CLBMON-40 Terms of Reference.
MQ-3 Which habitats and wetland features within the drawdown zone in Revelstoke Reach are utilized by waterbirds and what are their characteristics (e.g., foraging substrate, vegetation, elevation and distance to waters' edge)?	• Cartier Bay and Airport Marsh are key wetlands in the drawdown zone. Variable habitat in Airport Marsh sustains a high diversity of waterbird species during migration and breeding (especially waterfowl). • Within Cartier Bay and Airport Marsh, no clear correlation between dabbling duck use and aquatic vegetation type emerged. • There were several sites where shorebirds were more likely to be seen resting or foraging (albeit sporadically) during the fall migration. • During the breeding season, Short-eared Owl and Northern Harrier used the vast low elevation grassland areas for foraging and nesting, whereas Bald Eagle and Osprey foraged in ponds or within the reservoir pool, and nested above the drawdown zone in upland forest habitat. • Waterfowl brood-rearing primarily occurred in drawdown zone wetlands or in the shallow flooded and vegetated margins of the reservoir pool.
MQ-4 What is the annual variation in summer productivity (reproduction) of waterbirds in Revelstoke Reach and do indices of waterbird productivity vary spatially (e.g., are there areas of higher waterbird productivity)?	• There was considerable variability in the number of broods observed among years. • Canada Goose broods typically emigrated out of the brood survey area during the monitoring season, congregating further south in flooded grasslands (e.g., at Hall's Landing). The timing of this brood migration varied among years depending on reservoir levels, resulting in variable annual brood count data. • Downie and Airport Marsh appeared to be consistently important brood-rearing sites for other brood-rearing waterfowl. Apart from Canada Goose, most ground nesting waterfowl were impacted by reservoir-mediated nest flooding, which appeared to contribute to annual variability in brood counts. • From 2009 through 2017 there were as many as 7 and 12 Bald Eagle and Osprey nests respectively, and each year there were between 3 to 7 successful Bald Eagle nests, and between 0 to 7 successful Osprey nests. • There was evidence that as many as 3 Short-eared Owl (SEOW) nests were active in 2010 and 2 nesting pairs initiated two nests each in 2016. In all other years, no SEOW nesting occurred. • The leading cause of nest failure for SEOW was flooding. Predation likely ended all other nesting attempts we monitored. • Northern Harrier nesting attempts took place in 2 of 9 years. 1 of 3 was successful. • Osprey nests situated on the east shore of Revelstoke Reach fledged more young than nests on the west shore.

Management Question	**Summary of Key Monitoring Results**
MQ-5 Which waterbird species have the greatest exposure to being highly impacted by reservoir operations?	• The most important impact of reservoir operations to waterbirds is likely the impacts to productivity of ground-nesting waterbirds via nest flooding (e.g., Mallard, American Wigeon, Spotted Sandpiper, Killdeer, Spotted Sandpiper, Northern Harrier and Short-eared Owl). • The data indicate potential that Osprey productivity is influenced by June rainfall. • Waterbirds appeared to be able to find suitable stop-over and staging habitat within the drawdown zone during the migration regardless of the variable reservoir levels that were observed. As such, we infer that impacts to migrants are relatively minor.
MQ-6 Do reservoir operations (e.g., daily and maximum monthly water levels) influence the distribution and abundance of waterbirds and shorebirds in Revelstoke Reach?	• Using water depth as a measure of reservoir operations, and probability of detecting waterfowl as an index of their distributions, we showed that distributions can be highly influenced by reservoir operations. • There is no indication that overall waterfowl abundance was influenced by reservoir elevations. • The annual diversity of shorebirds appeared to be minimally influenced by reservoir elevations, variability in shorebird diversity was likely influenced by factors external to what was monitored by this study. • The diversity of waterfowl appeared to be influenced by reservoir elevations early in the fall migration with greater diversity being recorded in years when reservoir elevations were higher. • The latter trend was driven by diving species that moved into wetlands when inundated. • We suggest that diversity is more informative when measured within foraging guilds. Otherwise, high diversity could simply reflect a re-distribution of some species (e.g., diving birds), and reflect compromised foraging for other species.
MQ-7 To what extent do water levels in Arrow Lakes Reservoir influence indices of waterbird productivity in Revelstoke Reach?	• Note that the brood survey index of productivity is highly sensitive to variable detectability of broods related to reservoir levels; for example, as reservoir levels flood tall grass and shrubs, the mobile broods may become hidden in these habitats (see also discussion of Canada Goose in MQ-4 above). • Nest flooding was an important source of nest mortality for dabbling ducks, but not for Canada Goose. • Short-eared Owl and Northern Harrier are highly exposed to being impacted by reservoir operations via nest flooding because they nest on the ground. • June rainfall has been shown to be the primary predictor of Osprey productivity.
MQ-8 Can minor adjustments be made to reservoir operations to minimize the impact on migrating waterbirds or on indices of waterbird productivity?	• The 2012 surcharge resulted in loss of floating bog habitat, cattail habitat, and erosion of reservoir banks. Avoiding surcharge conditions would benefit waterbird productivity by avoiding destruction of habitat. • Wetlands are avoided by dabbling ducks when inundated by the reservoir; minor adjustments that can minimize inundation of key wetlands would benefit many waterbird species by keeping these habitats in optimal state (not inundated) for migrating waterbirds. • The soft constraint to match 1984 to 1999 reservoir operations (above 434 m ASL) during spring and summer was not observed/implemented but were unlikely to be effective mitigation measures. • It is likely that adjustments required to minimize impacts to productivity will not be classified as ‘minor’ in most years. Waterbirds nest over a wide range of elevations. • Annual flooding of grassland habitat prior to April 20th would preclude Short-eared Owls from nesting in the drawdown zone.
MQ-9 Can physical works be designed to mitigate any adverse impacts on migrating waterbirds or on indices of waterbird productivity resulting from reservoir operations?	• Construction of wetlands for waterfowl and wetlands for shorebirds positioned near or above the full pool elevation could be pursued, and it is likely that these would have a high probability of success. • Possible sites for waterfowl and/or shorebird habitat enhancements can be found at Downie Ponds, Airport Marsh, Airport West, 12 Mile, McKay Creek, and Catherwood. • Protection of Airport Marsh from reservoir operations during the breeding season would enhance productivity.
MQ-10 Does revegetating the drawdown zone affect the availability and use of habitat for waterbirds in Revelstoke Reach?	• All revegetation treatments were terrestrial, so did not influence waterbird foraging habitat. • Waterfowl nests were not located in revegetation treatment areas.

Management Question	Summary of Key Monitoring Results
MQ-11 Do physical works projects implemented during the course of this monitoring program increase waterbird abundance, or species richness, or indices of waterbird productivity?	• WPW6A and WPW15 were completed. • Neither WPW projects increased amount of waterbird habitat in the drawdown zone or affected productivity. • Both WPW projects prevent erosion and do not directly mitigate adverse impacts of reservoir operations on waterbirds. • Both WPW projects protect highly important habitats for waterbirds. • If WPW6A is successful in preventing erosion, it will have been effective (CLBMON-40 does not monitor erosion rates). • WPW15 has successfully maintained a minimum water level in Cartier Bay

KEYWORDS

River regulation, reservoir operations, waterbird, waterfowl, shorebird, Bald Eagle, Osprey, Northern Harrier, Short-eared Owl, nest success, habitat distribution, habitat use, migration, Arrow Lakes Reservoir, BC Hydro, British Columbia.

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Ian Robertson provided very helpful high-level guidance and reviews of reports as a senior advisor to BC Hydro. Initially, Dr. Alan Burger (UVic) provided guidance on development of our study design. After project start up, Dr. David Green (SFU) provided guidance on our overall strategy and methods used for studying waterbirds as we worked closely with SFU on CLBMON-36 and CLBMON-39. Bruce Enns provided initial GIS support. Tracey Hooper provided detailed reviews of annual reports.

From 2014 to 2017, Cooper Beauchesne and Associates (CBA) collaborated with the Okanagan Nation Alliance (ONA) for delivery of CLBMON-40, with ONA biologists and technicians providing field and technical support, and insight into the perspectives and protocols of the Syilx (Okanagan) people. Bruce Weaver of the Okanagan Indian Band, and Autumn Solomon, Alexis Friesen, Karle Zelmer, Kayla Williams, and Michael Dunn of the ONA contributed to field studies. Al Peatt and Dave DeRosa managed the ONA's involvement and provided report reviews.

At the heart of this project is the data collection; we thank everyone who was involved with this task for their willingness, good attitudes, and expertise: Pierre-Paul Bitton, Kevan Cowcill, Paul Levesque, Brad Stewart, Jeannine Randall, Catherine Craig, Devon Anderson, Michal Pavlik, Corey Bird, Rudy Badia, Chris Joseph (Ktunaxa FN), Lucie Parker, Jennifer Greenwood, Alan Carson, Leonard Edwards (Splatsin FN), Raven Douglas (Splatsin FN), Stacey Carnochan, Russell Cannings, Jason Fidorra, Emily Braam, James Bradley, Ryan Gill, Harry van Oort, Suzanne Beauchesne, John Cooper, and Emily Smith conducted field studies on waterbirds. Harry van Oort and Ryan Gill conducted most aerial surveys, assisted by Catherine Craig. We would like to thank Selkirk Mountain Helicopters and Canadian Helicopters for providing exceptionally safe and consistent piloting on aerial surveys, and personnel at BC Hydro Aircraft Operations for helping to ensure that our flying was performed in safe flying conditions. Ryan Gill and John Cooper co-managed this project. Suzanne Beauchesne provided logistical coordination to assure that the resources and staffing were in place.

Harry van Oort led this project for the first nine years, provided scripts and continued, valuable guidance through to the completion of this report.

A draft report was submitted by CBA in November 2018. While all 10 years of data collection and reporting were completed by Cooper Beauchesne and Associates, the final revisions to this report were done by Hemmera Environchem Ltd.

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1 INTRODUCTION

The Columbia River is one of the most modified river systems in North America (Nilsson et al. 2005); its flow is regulated by multiple hydroelectric dams and water storage reservoirs. Water storage reservoirs positioned in succession along the main stem of the Columbia River in British Columbia include the Kinbasket Reservoir (Mica Dam, 1973), Lake Revelstoke (Revelstoke Dam, 1984) and Arrow Lakes Reservoir (Hugh Keenleyside Dam, 1968). Following the completion of these projects, few areas of natural riparian habitats and wetlands remained in the floodplain and valley bottom of the Columbia River valley[1]. The footprint areas of these reservoirs have removed or altered much of the valley-bottom habitat, and their drawdown zones are typically comprised of steep shorelines (Enns et al. 2007, Utzig and Schmidt 2011). In the upper elevations of the drawdown zones, the growth of riparian and wetland vegetation is possible, but such habitats are uncommon (Enns et al. 2012, Miller et al. 2015).

Development and operation of reservoirs is known to have significant but variable effects on wildlife, including waterbirds (Nilsson and Dynesius 1994, Stevens et al. 1997, Reitan and Thingstad 1999). Effects are usually the result of changed hydrology, especially flow patterns and inundation (Baxter 1977, Kuiper et al. 2014). In general, waterbird distribution on reservoirs can vary greatly as a direct function of water levels or indirectly through effects of water levels on habitat (e.g., Lorenzón et al. 2017). Important habitat attributes such as vegetation cover and foraging substrates may be exposed or submerged, and fluctuating water depth may affect the quality, distribution, and availability of foraging resources for waterbirds (Rundle and Fredrickson 1981, Parsons 2002, Baschuk et al. 2012).

Like the impacts from reservoir operations, riparian habitat in natural settings is subject variations in the hydrological cycle, however, reservoir operations do not generally mimic natural hydrological regimes and thus there are impacts to riparian ecosystems in a regulated environment that are not seen in natural systems (Nilsson and Berggren 2000, Anteau et al. 2014).

Although there are few studies available, some reservoir operations have been shown to change the annual cycle of vegetation growth and affect migrant/winter waterfowl populations (Guan et al. 2014). Most effects of reservoir operations are broadly negative for birds, but changes to reservoir operations can positively affect the quality of food resources available to waterfowl in some cases (e.g., Guan et al. 2016).

Remnant wetlands associated with reservoirs can provide substantial wildlife habitat value but are often affected by reservoir operations (Desgranges et al. 2006). At the north end of the Arrow Lakes Reservoir (ALR), Revelstoke Reach (Figure 1) provides a relatively high concentration of productive wetland habitat, including a reservoir-altered bog, an extensive and diverse cattail/bulrush marsh, and several ponds. The rarity of such habitats in the landscape makes Revelstoke Reach an area of great regional importance for

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[1] It has been estimated that 7,700 ha of wetland habitat have been impounded in the Canadian portion of the Columbia basin (Utzig and Schmidt 2011). The wetlands in Revelstoke Reach are the only significant wetland habitats between Valemount and Castlegar, an approximate linear distance of 400 km of valley bottom that was impounded in this region. An additional 100 km of valley-bottom habitat was flooded between Mica and Donald along the Columbia Reach of Kinbasket Reservoir.

wetland wildlife (Tremblay 1993, Jarvis and Woods 2001, CBA 2013, CBA 2013a, CBA 2013b).

In addition to these natural and modified habitats, extensive revegetation efforts have been undertaken in the Upper Arrow Lakes Reservoir (ALR), beginning with reed canarygrass for erosion control, and more recently with sedge plugs and deciduous shrub-staking for wildlife habitat (Moody 2005, Keefer and Moody 2010, Kellner and Bird 2017).

During the Columbia River Water Use Planning process, a number of potential impacts from reservoir operations on waterbirds in Revelstoke Reach were identified as key wildlife management concerns by the Consultative Committee (BC Hydro 2005). Through this consultative process, the operation of ALR was identified as having a potential impact to the availability and quality of habitat in Revelstoke Reach for waterbirds (e.g., loons, grebes, waterfowl, four species of raptors, and shorebirds). Prior to this study, how reservoir operations influence waterbird use of the ALR drawdown zone had not previously been studied in detail, and the relationship between reservoir operations and waterbird distribution or habitat quality was poorly understood. As a result, Water Licence Requirements study CLBMON-40 was developed to improve understanding of how reservoir operations affect waterbirds in Revelstoke Reach.

CLBMON-40 field studies were initiated in 2008 and completed annually through 2017. Each year an annual report was produced that summarized the results of field studies (CBA 2009-2018). An interim comprehensive report, with multi-year analyses, was produced after five years (Cooper Beauchesne and Associates 2013a). The ten years of data provide one of the most comprehensive datasets on waterbirds and reservoirs available in the world. This report provides comprehensive results from the 10-year study and is organized to address the specific Management Questions developed by BC Hydro.

1.1 Objectives

The objectives of CLBMON-40 were:

- Determine the extent of use of Revelstoke Reach by waterbirds by determining their abundance, species richness, distribution, productivity, and patterns of habitat use.
- Inform BC Hydro on how reservoir operations affect waterbirds by monitoring their abundance, species richness, distribution, productivity, and patterns of habitat use over time.
- Determine whether minor adjustments can be made to reservoir operations to minimize the impact on waterbirds or whether mitigation strategies are required to reduce the risks to these populations from reservoir operations.
- Provide the data necessary to inform how physical works projects may enhance waterbird habitat in Revelstoke Reach.
- Provide the data necessary to evaluate whether physical works projects or revegetation initiatives enhance waterbird habitat in Revelstoke Reach.

This report addresses 11 Management Questions designed to meet these objectives.

1.2 Addressing Management Questions

In the following section, each management question is answered with the data acquired over the course of this project, or by professional opinion if it cannot be addressed with the data. Extensive statistical analyses have been conducted to arrive at the conclusions presented, the details of which are contained in the appendices of this report. Here, only the results and discussion necessary to answer each MQ are presented.

The management questions changed over the course of the study; this report addresses the MQ's included in the 2015 revision of the terms of reference for CLBMON-40 (BC Hydro 2015).

The management questions outlined in the Terms of Reference are focused on waterbirds which are defined as the guild of birds which are associated with wetland or aquatic features. These include:

- waterfowl (diving and dabbling ducks, grebes, cormorants, swans, geese, coots and rails)
- shorebirds
- gulls, terns and herons
- water-dependent birds of prey (Bald Eagle and Osprey)

In addition, Short-eared Owl and Northern Harrier are considered as they were previously known to nest in habitat vulnerable to reservoir operations.

Throughout this report the term waterbird refers to all guilds of wetland dependent birds, but specific MQ's address guilds within the waterbirds (waterfowl, raptors and shorebirds are treated separately for the MQ's relevant to those genera).

For some analyses it was practical to only consider dabbling ducks (*Anas spp.*) because this group of waterfowl have common habitat requirements and were in some cases the most numerous species to consider.

There was no specific focus on the gulls and terns as species in these genera occur in low numbers in the study area. Great Blue Heron was enumerated during surveys, but were treated separately from other guilds, and no specific MQ's were focused on them.

2 STUDY AREA

Revelstoke Reach extends north of Shelter Bay, to the Revelstoke town site, and is bounded by the Monashee and Selkirk Mountains to the west and east, respectively (Figure 1). This area lies within the interior wet belt of British Columbia (ICHmw2 and ICHmw3) and receives much of its precipitation as snowfall delivered by Pacific frontal systems in winter (Meidinger and Pojar 1991).

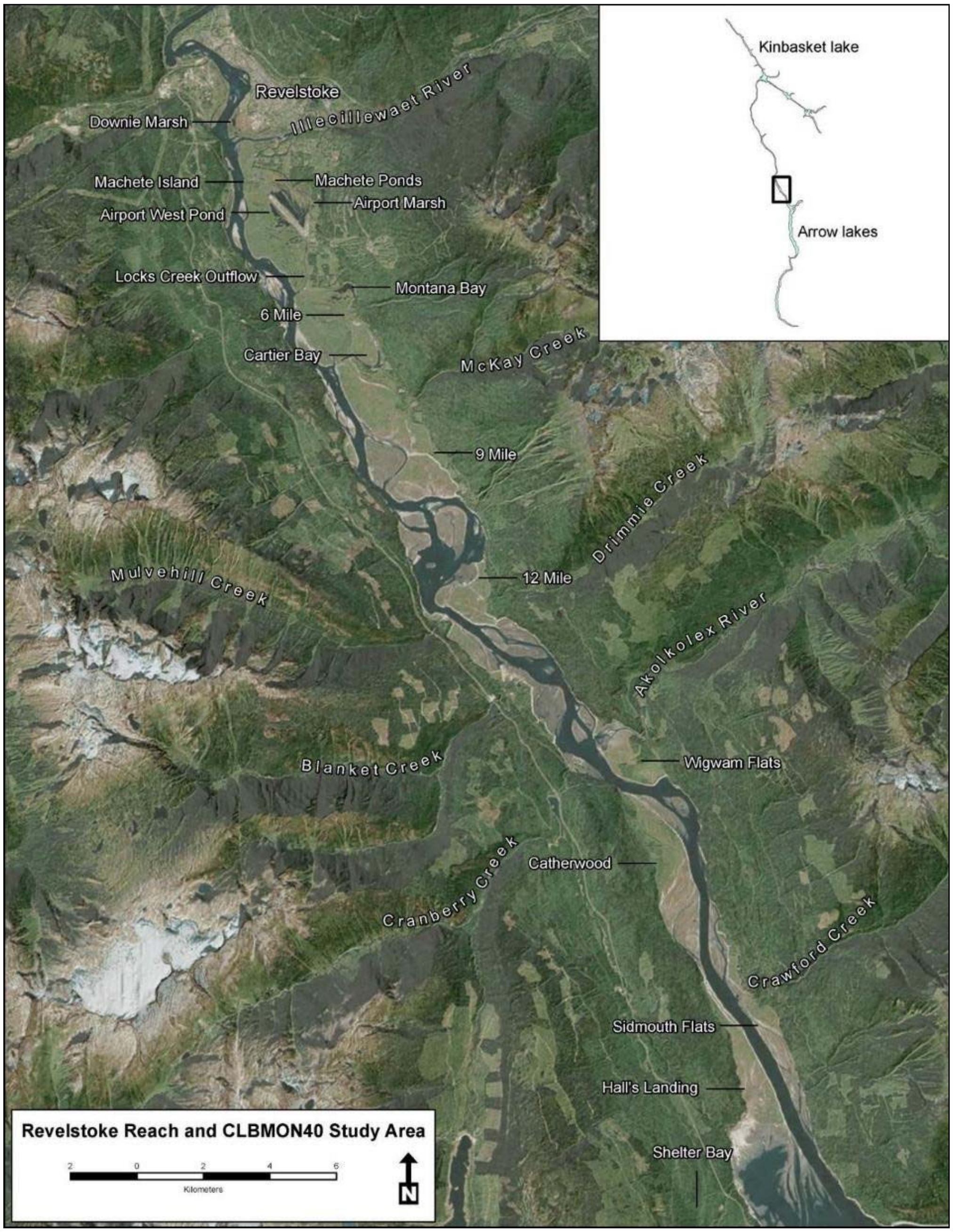

Figure 1: Overview map of Revelstoke Reach, with geographic features labelled. Note that this image shows the reservoir at very low levels; at full pool conditions, most of the valley bottom in this map becomes flooded.

The Columbia River flows south along Revelstoke Reach from the Revelstoke Dam towards the ALR. Most parts of Revelstoke Reach are inundated by the reservoir when the pool elevation is at its maximum, which occurs during the summer in most years. When water levels are sufficiently low (e.g., in winter and spring), Revelstoke Reach consists largely of a level floodplain vegetated primarily by reed canarygrass (*Phalaris arundinacea*) and sedges (*Carex* spp.). The subtle topography of the valley floodplain was shaped by the erosion and deposition of material from the Columbia River, and contains oxbow features, back channels, gravel shoals, and sand banks. Historically, this area was naturally forested by western redcedar (*Thuja plicata*), Engelmann spruce (*Picea engelmannii*), white pine (*Pinus monticola*) and black cottonwood (*Populus balsamifera*). Prior to the completion of the Hugh Keenleyside Dam near Castlegar, Revelstoke Reach was cleared for farming and contained the Arrowhead branch of the Canadian Pacific Railway. The old roads and rail grades influence the hydrology of the study area in some locations.

Permanent wetlands are primarily situated at the northern end of Revelstoke Reach. They include several natural and human-made ponds, a large cattail marsh near the Revelstoke Airport (Airport Marsh), and a bog wetland in Montana Bay. Cartier Bay contains an oxbow lake. These three wetlands are situated at different elevations (between 433 and 438 m above sea level (ASL)). There are many small flooded depressions scattered throughout the study area. The Revelstoke Reach floodplain gradually decreases in elevation towards the southern end of the reach; therefore, the southern end is flooded for longer periods and is more sparsely vegetated than the northern end. Extensive tracts of non-vegetated habitat (sand or silt) are present at low water levels (Korman 2002).

3 ARROW LAKES RESERVOIR OPERATIONS

The Arrow Lakes Generating Station adjacent to the Hugh Keenleyside Dam is a relatively small component of the Columbia generation system; the ALR is operated primarily by BC Hydro for downstream flood control and power generation in the USA. Reservoir surface elevation is influenced by precipitation and spring climate (rain, snow, and freshet), and controlled by discharge from the Mica and Revelstoke Dams upstream, and by outflow from the Hugh Keenleyside Dam and Arrow Lakes Generating Station. The reservoir is licensed to operate between elevations of 418.6 m and 440.1 m (BC Hydro 2007). With approval from the Comptroller of Water Rights, the maximum allowable level is 440.75 m. Since 1968, the typical operation of Arrow Lakes Reservoir has involved storing water during the spring freshet and drafting the reservoir in fall and winter. Consequently, the reservoir elevation cycles annually, with high water levels in summer and low water levels in late winter/early spring (Figure 2).

During the study, observed operations were representative of historic operations in many respects, including a normal range of elevations within seasonal time periods (Figure 2). Within that normal range, there was variability among years, which provided information on the effects of different filling regimes. One notable feature of the operations that occurred during the study period is that they were biased to be higher than historic during the spring; that is, the rising limb of the hydrographs was advanced in all years by up to three weeks, relative to historic operations (Figure 2).

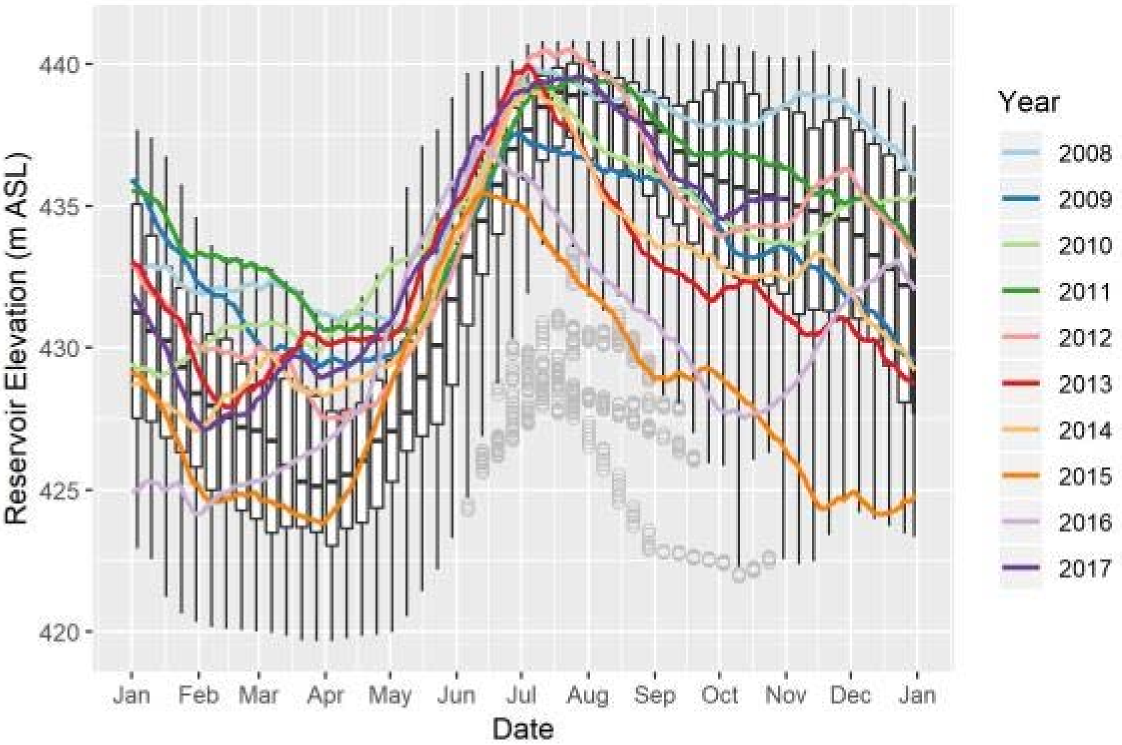

Figure 2: Annual reservoir operations during the study period (2008-2017) shown by the coloured lines, with historic reservoir operations plotted as a boxplot.

4 METHODS

4.1 Overview

Comprehensive methods are provided in an annual protocol report written primarily for field technicians (Cooper Beauchesne and Associates 2017a). Analytical methods used to answer each management question are included in the Appendices.**Error! Reference source not found.** A brief description of the methods used for CLBMON-40 is provided below.

CLBMON-40 included six types of waterbird surveys that occurred annually (Figure 3). The surveys were designed to answer each of the Management Questions for the guild of waterbird it was intended for:

1. land-based waterbird surveys in spring, during the brood rearing season, and in fall (MQ's 1, 3, 5, 6, 8, 10, 11);
2. aerial waterfowl surveys in spring and/or fall (MQ's 1, 3, 5, 6, 8, 9, 10, 11);
3. land-based shorebird surveys during the fall migration (MQ's 1, 3, 5, 6, 8, 9, 10, 11);
4. boat-based shorebird surveys during the fall migration (MQ's 1, 3, 5, 6, 8, 9, 10, 11);
5. productivity monitoring of Bald Eagle and Osprey (nest monitoring) (MQ's 4, 7, 9, 11); and
6. productivity monitoring of Short-eared Owls and Northern Harriers (nest monitoring) (MQ's 4, 7, 9, 11).

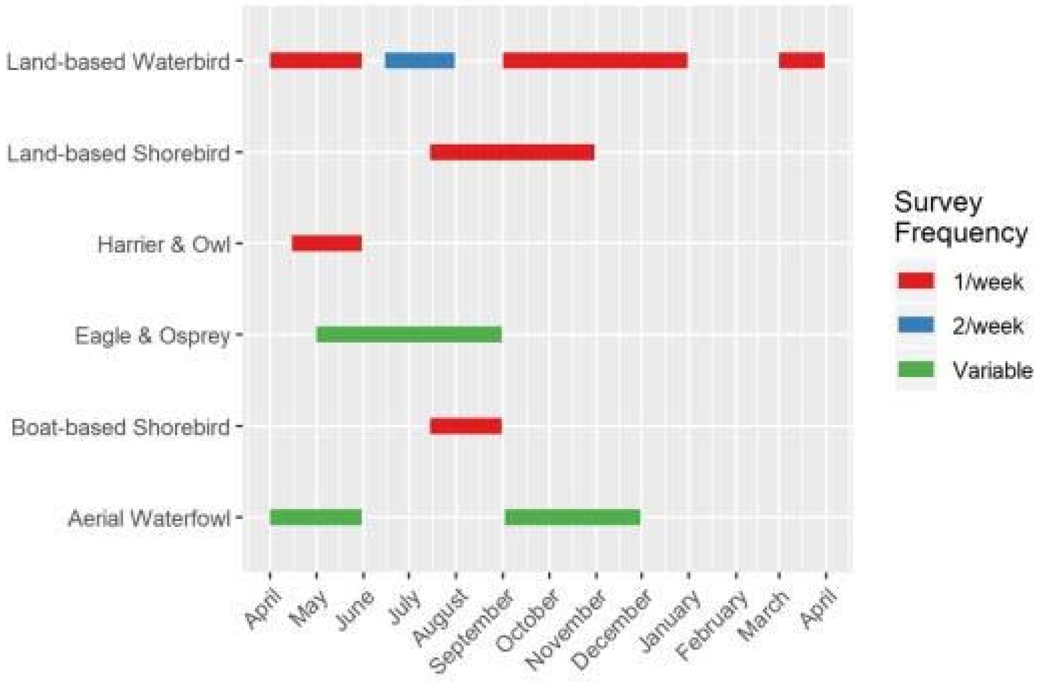

Figure 3: Overview of how the CLBMON-40 monitoring surveys were scheduled. Land-based waterbird surveys were conducted 2x per week during the brood-rearing period (June and July).

4.2 Data Sets

Over ten years of implementation, CLBMON-40 generated a wealth of data that can be used to address management questions. In accordance with the six survey methods introduced above, there are six different data sets which are described below.

4.2.1 Land-based Waterbird Data

Land-based surveys recorded detailed observations of waterbird use at suitable and accessible wetlands, including what is confirmed to be the most suitable habitats in the study area, and likely the most notable wetlands in the region. The land-based waterbird survey data covers 10 years, including 10 spring migrations, 10 brood-rearing periods, 10 fall migrations, and 5 winter periods (2009-2013). Data was gathered from all weeks of the year except from mid-July and August (Figure 3). The fixed survey route included 23 independent stations viewing 10 sites, with 12 of these stations being reliably accessible and monitored on all survey occasions[2]. In total there were 413 surveys completed, generating 22,858 observations, with each observation being a spatially explicit count for particular bird classes (based on species, age, and sex).

During the brood-rearing period, the survey also collected data on the presence, size, and age of waterfowl broods. When broods were encountered, broods were aged according to

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[2] After the Year 5 interim report we focussed on wetland habitats for the waterbird survey and dropped survey stations overlooking open channel habitat.

Gollop and Marshall (1954), and in addition to counting the brood size, the numbers of broods were counted in the cases where multiple broods were grouped together. When multiple broods converged, as often is the case with Canada Goose, the number of broods was estimated, based on the number of attending adults.

While the land-based survey data captures a robust and detailed account of habitat use at important wetlands, the data set has spatial limitations due to the limited accessibility throughout the study area, and also due to limited scope of view afforded a survey stations. To reduce the latter issue, survey stations were specifically chosen to maximize viewing potential and to allow year-round access regardless of road and reservoir conditions, but some wetlands had hidden sectors which were essentially blind spots in this survey (e.g., at Airport Marsh).

4.2.2 Aerial Waterbird Data

The aerial survey dataset complimented the land-based waterbird dataset by allowing all parts of the study area to be surveyed. These data provided less detail on waterbird communities and their habitat-use, but considered the entire study area, rather than just wetlands. The aerial surveys were conducted as a complete census of the study area, capturing habitat use in all areas at different reservoir levels. The resolution of this dataset was less fine-grained than the land-based surveys due to the need for quick identification of species, and assignment to general habitat classes. The entire study area was sub-divided into 130 polygons, each classified as one of five habitat types (Table 4-1).

Table 4-1: Aerial polygon habitat types and distribution.

Habitat Type	Description	Area (hectares)	Proportion of Study Area
Channel	Open river channel	2435	41%
Grass	Grassland habitat	2239	38%
Grass/shrubs	Matrix of grassland and shrubs	247	4%
Unvegetated	Low elevation silt, sand or cobble	818	14%
Wetlands	Water, or aquatic vegetation dominated	201	3%

Polygons were delineated based their elevation and habitat type. During the survey, the level of inundation was recorded at each polygon. Using a real time GPS location on a digital map, observations of waterbirds could be assigned to polygons even when they were underwater. Spatially, habitat use was characterized by assigning observations of waterbirds to uniquely identified polygons, rather than by mapping exact locations of waterbirds within habitat features (as per the land-based surveys).

Aerial surveys were less useful for determining detailed habitat use but were better suited for examining the distribution of waterbirds among wetlands and throughout the study area.

The aerial waterbird surveys were used to answer MQ's related to distribution, abundance, and timing of migration of waterbirds. Between 2009 and 2017, we conducted 62 aerial surveys (making 6205 observations of 402811 birds) timed to coincide with the period surrounding maximum spring and fall migration. Once a comprehensive dataset at a range of dates and reservoir elevations had been collected, this effort was scaled back to focus on surveying at reservoir elevations which had few data points.

4.2.3 Shorebird Data

This data set is much like the land-based waterbird data, but includes observations made from boat, as well as from land. Shorebird surveys were conducted annually for nine of the ten years of the project and were timed to capture the fall migration only. Together, the land-based and boat-based surveys allowed isolated wetlands and reservoir shorelines to be monitored, and the combined data provides a good representation of shorebird usage throughout the entire study area.

Land-based shorebird surveys were conducted weekly and were designed to capture sites with high suitability for migrating birds. For the first five years, boat-based surveys were conducted every second week, but as the timing of migration became better understood, we compressed boat surveys into the first six weeks to better capture use at the most suitable sites which were only boat accessible. Boat-based shorebird survey results were pooled with the land-based shorebird survey data for surveys conducted in the same week. As with land-based surveys, core sites which were consistently surveyed were used as a subset of the entire dataset for analysis.

A total of 121 land-based and 47 boat-based surveys were conducted between 2008 and 2016. Survey locations varied throughout the study period, but a core set of stations were surveyed consistently, these core sites captured the most suitable habitat and were surveyed throughout the study period (Appendix 7.12). Surveys were discontinued in 2017 as sufficient data had been gathered to answer MQ's relevant to this taxon. Over this period we made 1206 observations of 13 shorebird species.

Shorebirds were identified to species as often as possible, but we often lumped *Limnodromus* sp. together as 'Dowitcher sp.', *Calidris* sp. sandpipers as '*Calidris* sp.' and both Greater and Lesser Yellowlegs as 'Yellowlegs sp.'.

Due to the fine scale of habitat use by this taxon (typically the shoreline which moved locations depending on reservoir elevation) we did not place emphasis on high resolution mapping of habitat use, but instead assigned observations to survey stations.

4.2.4 Bald Eagle and Osprey Data

Bald Eagle and Osprey productivity was monitored between 2008 and 2017. These data include information about nests, and their usage across years. Nests were monitored by boat- and land-based methods until 2014 when we opted to use a helicopter. Use of the helicopter improved our ability to determine nest contents, and the fate of each nest, thus improving the quality of the dataset over the last four years of the project.

Each spring a survey of known nest locations was conducted while simultaneously searching for new nest locations. Over the course of the study, 51 nests were monitored with 192 known outcomes (nests are re-used across years for these species); of these, 17 were Bald Eagle nests and 34 were Osprey nests.

In 2014, the study area was extended to include Beaton Arm, where eight of these nests occurred. The purpose of expanding the study area was to capture variability in nest productivity in a naturally lentic ecosystem, for comparison with the nests in the primary study area, which are positioned along the corridor of the Columbia River thalweg.

4.2.5 Short-eared Owl and Northern Harrier Data

Surveys for Short-eared Owl and Northern Harrier occurred concomitantly every spring. Surveys were timed to begin as these species were arriving on their breeding grounds (mid-April), and continued until nesting status was determined (late May). If breeding was known or suspected, but nests had not been located prior to the end of this field component, nest surveys were continued under a different WLR study (CLBMON-36) as sites overlapped with known breeding areas.

Over the 10-year period, 121 early morning or evening surveys were completed, generating 82 observations of Short-eared Owl, and 191 observations of Northern Harrier. Five Short-eared Owl nests and three Northern Harrier nests were monitored until their outcomes were determined. Both species nested at irregular annual intervals in the study area, leading to a paucity of data on these species.

4.3 Analysis

Data analysis and graphical presentation were done using R and associated libraries for statistical analysis (R Core Team 2015). We present data graphically for datasets with clear trends and for easier consumption of data. Statistical analyses were used to determine significance, or delineate subtle trends, not obvious with data presentation. Spatial analysis and map generation was done using a combination of Python and ArcGIS software.

5 MANAGEMENT QUESTIONS

5.1 MQ-1 What is the seasonal and annual variation in the abundance and spatial distribution of waterbirds within the Revelstoke Reach during migration?

5.1.1 Waterfowl Migration

Abundance of waterfowl during migration varied annually with yearly maximum one-time counts during fall migration ranging from a low of 586 waterfowl in 2015, to a high of 1733 in 2008. Accounting for survey effort during the migratory period, 2016 had the highest average rate of detection with 719 waterfowl/survey and 2015 had the lowest detection rate with 517 waterfowl/survey (Figure 4, Appendix 7.1). Variability in abundance among years did not follow any obvious trends, with high and low years occurring throughout the study period (Figure 4).

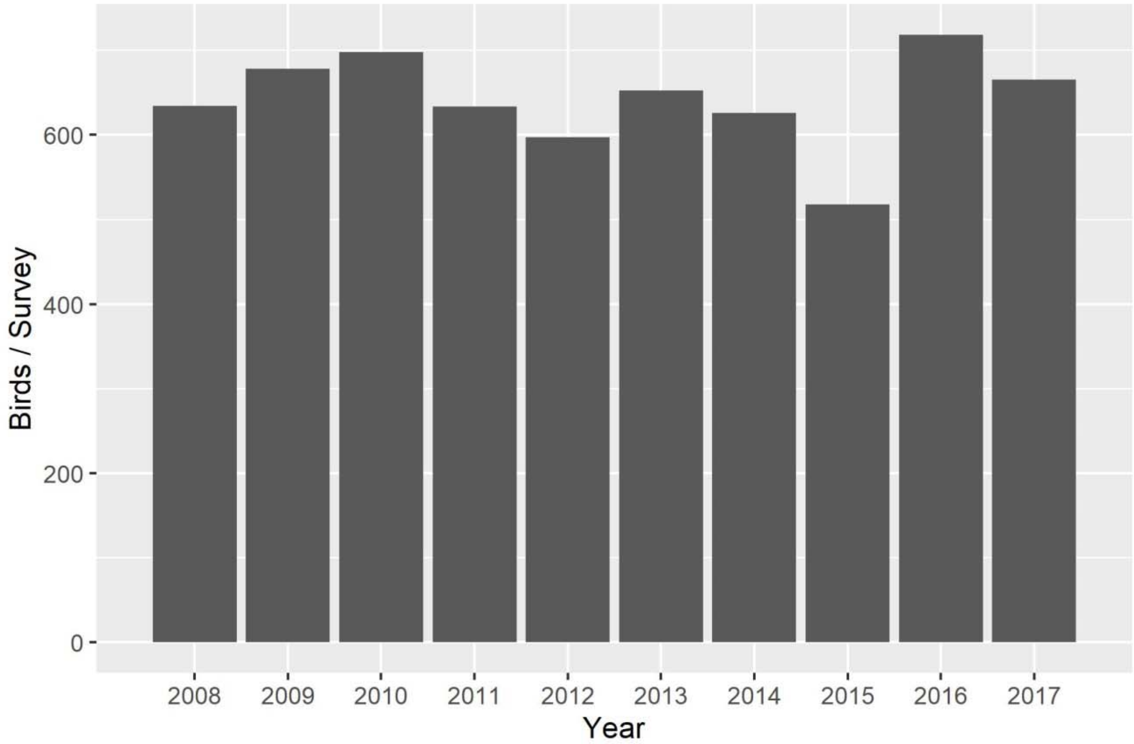

Figure 4: The average number of waterfowl detected per survey during migration for each year of the study.

Mean survey counts for fall migration of Canada Geese ranged from 101 (± 39) in 2015, to 360 (± 95) in 2011. For all other species of waterfowl, mean annual variation ranged from a low of 237 (± 101) in 2015, to a high of 662 (± 363) in 2009.

Daily counts and seasonal changes in abundance of waterfowl (excluding Canada Goose) were estimated for the key wetlands of Revelstoke Reach (Appendix 7.1). Two migration peaks were defined, one in the spring, centered around the second week of April, and the returning fall migration peak, occurring near the end of October (Figure 6). The fall peak is substantially higher (estimated peak = 567) than the spring (estimated peak = 408) likely due to the number of juveniles joining migration.

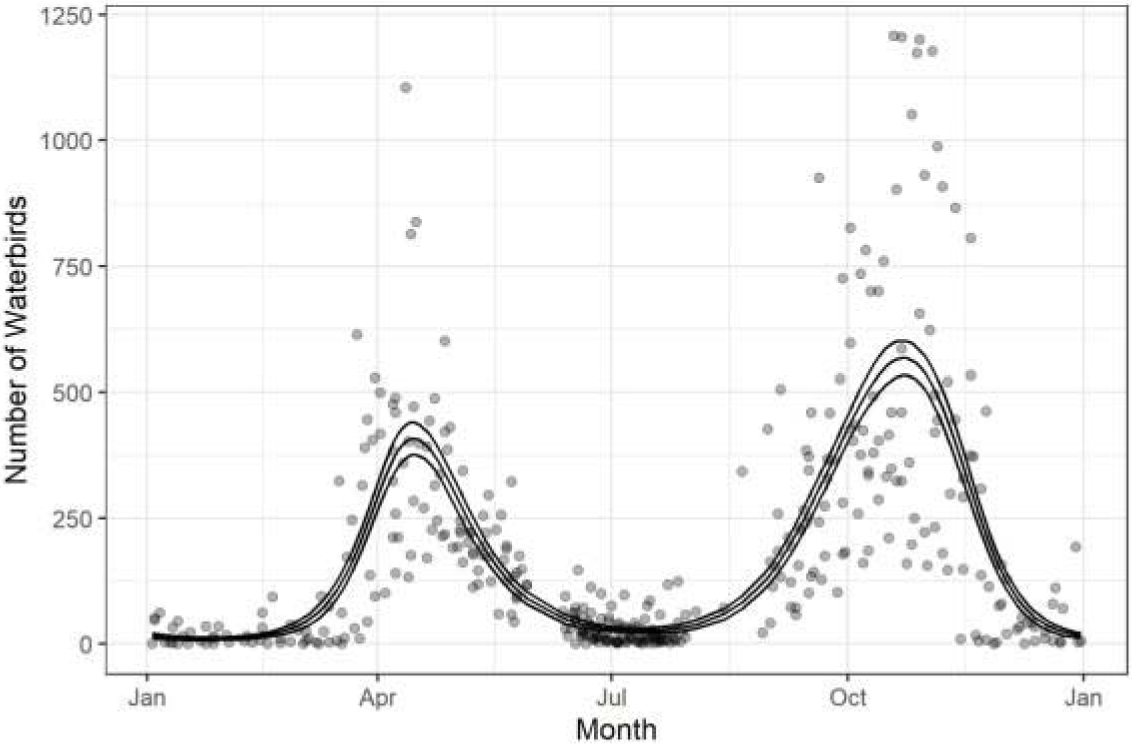

Figure 5: The total number of waterfowl (excluding Canada Goose) counted on each occasion of land-based waterbird surveys at the core wetlands continuously monitored for the duration of the project. Dates are standardized to one year. A negative binomial GAM was used to predict the smoothing function (Appendix 7.1.1).

Spatially, waterfowl were unevenly distributed throughout the study area during both spring and fall migration. Aerial waterbird surveys conducted during the spring and fall illustrate how birds disproportionately select wetlands over other habitat available in the study area, with Cartier Bay being the most heavily used wetland (Appendix 7.2). The wetlands Airport Marsh, Airport West, and Cartier Bay collectively accounted for 45% of waterbird detections (excluding Canada Goose) made during aerial surveys (Figure 6, Appendix 7.2). The deviation from the selection of wetland habitat that occurred during higher reservoir levels is explored in MQ-6.

Within wetlands, spatial variability was also pronounced, with higher densities of waterfowl congregating in certain areas. The density of waterbird use of each of the two most important wetlands indicated differing use by the two different guilds of waterfowl (diving vs dabbling ducks) within each wetland, with diving ducks congregating in deeper areas, and dabblers selecting shallower water (Appendix 7.16). The relationship between waterbird density and spatial variability within wetlands is explored in MQ-3.

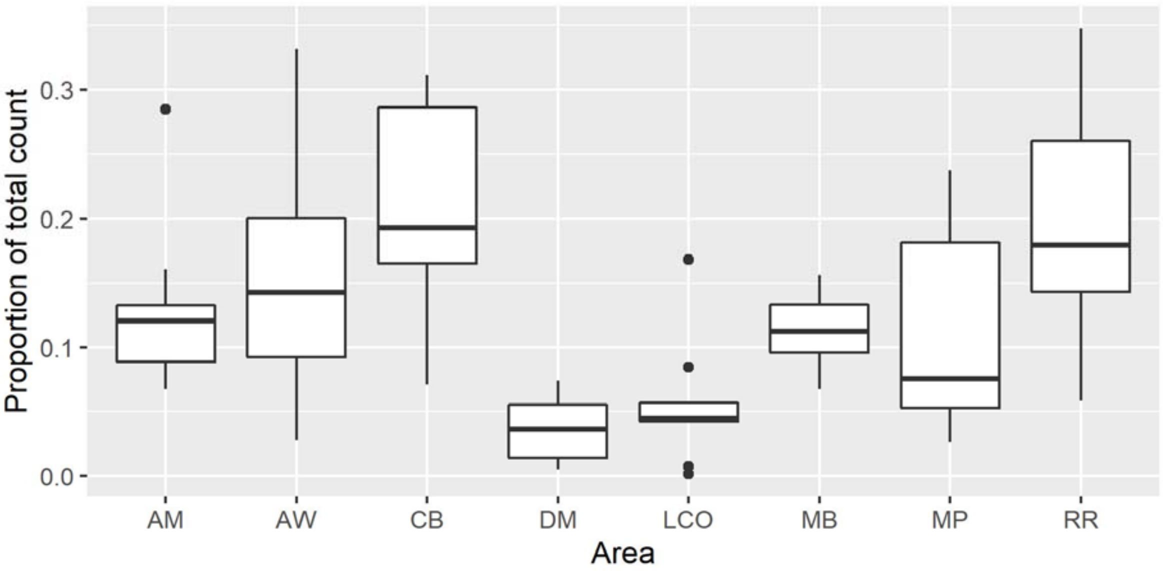

Figure 6: Distribution of birds among wetlands during aerial waterbird surveys (n = 18 in spring and 27 in fall). AM = Airport Marsh, AW = Airport West, CB = Cartier Bay; DM = Downie Marsh, LCO = Locks Creek Outflow, MB = Montana Bay, MP = Machete Ponds, RR = Revelstoke Reach.

Species composition of waterfowl detected on land-based surveys is compiled in Appendix 7.14 for each season surveyed (winter, spring migration, brood surveys, and fall migration). Canada Geese accounted for the largest proportion of migratory waterfowl each year, averaging 30% of the birds recorded on each survey occasion. American Wigeon (*Anas americana*), Mallard (*Anas platyrhynchos*), American Coot (*Fulica americana*) and Green-winged Teal (*Anas crecca*) round out the five most commonly detected species on the surveys.

Over the course of the ten-year study period we observed a steady decline in the number of species detected during land-based waterbird surveys (Figure 7). These results corroborate the reduction in diversity observed by Jarvis and Woods (2001), who noted a decline from 65 species in the early nineties to 41 species in 2000. Our study showed a decline from 52 species in 2008-2010, to a low in 2017 of 38 species (Figure 7). Both datasets suggest there is among-year variability in species richness, but that it is declining overall (Appendix 7.1.1).

The reduced numbers since the early 1990's suggests a strong decline, regardless of the differing datasets between the two studies. This runs counter to North America-wide waterfowl population trends, which have seen strong increases over the same period (North American Bird Conservation Initiative Canada 2019). On a local scale, the time period over which Jarvis and Woods noted declines, coincides with the beginning of revegetation of Revelstoke Reach for dust control (Jackson et al. 1995). It is possible that habitat changes from revegetation influenced the distribution, abundance, and diversity of waterfowl using the area during migration.

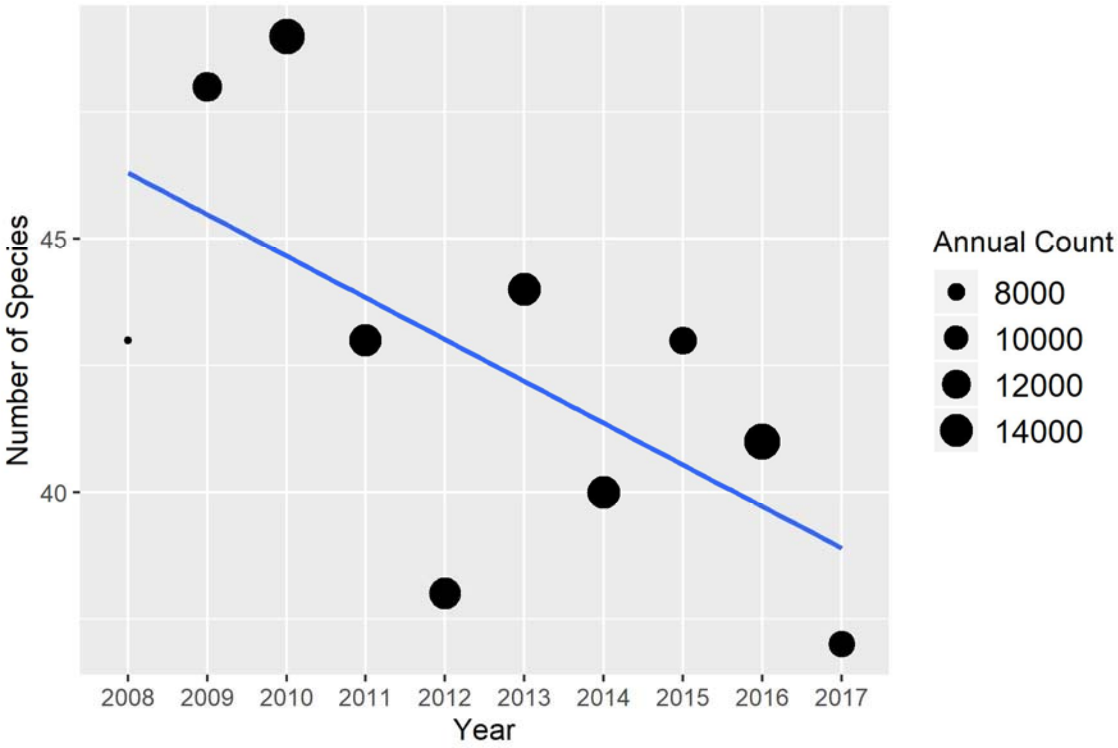

Figure 7: Trends in species richness and abundance of waterbirds over the 10-year study period. A decline in richness is shown by the blue line, with no associated trend in abundance over the same period. The cumulative count of observations ("Annual Count") in 2008 is substantially lower than other years due to incomplete counts that year.

5.1.2 Fall Shorebird Migration

Annual abundance and diversity of shorebirds varied drastically over the nine years that surveys were conducted, but results indicate that Revelstoke Reach is not a heavily used migratory route for shorebirds. Spotted Sandpiper (*Actitis macularius*) was the most common species and detected in stable numbers each year. However, other species occurred irruptively, often not being detected in some years and then appearing in larger numbers in other years (Figure 8). Baird's Sandpiper (*Calidris bairdii*), and Pectoral Sandpiper (*Calidris melanotos*) are examples of these irruptions.

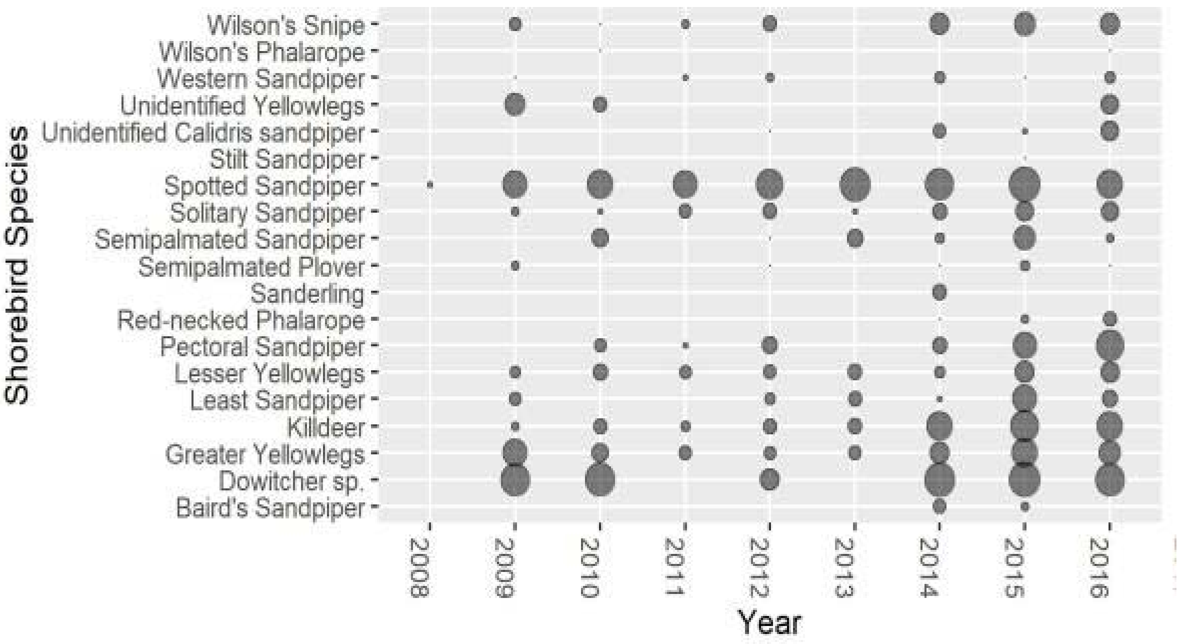

Figure 8: Shorebird species plotted over the year they were detected. Size of the dot indicates the number of birds. For display purposes, a logarithmic scale was used to scale the size of points. Spotted Sandpiper occurred in far higher numbers than any other species and would overwhelm the figure if true values were used.

Irruptive occurrences numbered in the dozens, not in numbers indicating a high degree of habitat use in the study area. Other *Calidris* spp. sandpipers occurred in low numbers and were distributed among the key areas but were most frequently observed in Cartier Bay and Locks Creek Outflow (Appendix 7.17).

Timing of migration of shorebirds was difficult to quantify due to the low numbers, and inconsistent presence, inter-annually, of many species. For this reason, we estimated timing of migration for the most commonly detected species (Spotted Sandpiper and Dowitcher sp.) which occurred in the highest numbers more consistently than other species (Figure 8). *Calidris* sandpiper migration was also estimated but given their infrequent occurrence the resolution of the timing of migration is low. The peak timing of this genus is slightly later in the summer than Spotted Sandpiper (mid-August, as opposed to a peak in early July). Spotted Sandpiper decrease in numbers from mid-July, when surveys began, through September (Appendix 7.17). Local breeding Spotted Sandpiper constitute a large proportion of detections during the early monitoring period, and these obscure the initiation of the true migration. Dowitchers were the latest migrant of all shorebird species and were detected in substantial numbers into November in years they were detected (Appendix 7.18).

Overall, shorebirds occur in low numbers during migration, and diversity is usually low, but with intermittent years of increased diversity by way of irruptions of *Calidris* sp. sandpipers.

Distribution of shorebirds throughout the study area varied with species. Spotted Sandpipers were distributed throughout Revelstoke Reach, and were found at almost every shorebird station surveyed, whereas Dowitchers were found only at specific stations where suitable muddy substrates were exposed (Appendix 7.17). *Calidris* sp. shorebirds were similar in their distribution to Dowitchers, except that a substantial proportion of *Calidris* sp. were detected on mud flats near the outflow of the Akolkolex River. Appendix

7.17 shows how the most numerous species (or genera) were distributed among the primary shorebird wetlands.

5.1.3 **Effects, Challenges, and Opportunities**

Sufficient data have been collected to answer this MQ. Seasonal variation was well established, with clear peaks occurring in the spring and fall; this seasonal variability was used to clarify impacts to reservoir operations in MQ-6.

5.1.3.1 Waterfowl

Detection of waterfowl during land-based surveys was high at low and very high reservoir levels, as survey stations were positioned to capture key habitats surveyed. However, during intermediate water levels as inundation of terrestrial habitat advanced, detectability of waterfowl decreased as flooded grassland habitat became available, and birds using this habitat became obscured. At reservoir levels between 435-437m ASL, detectability from land-based stations decreased the most; however, aerial surveys provided high detectability of waterfowl at all reservoir levels. Terrestrial habitat selection was inherently difficult to ascertain due to grass and shrubs obscuring birds from oblique angles. As well, birds roosting on the ground were often camouflaged when viewed during aerial surveys, likely reducing the number of birds detected than were actually using those habitats.

The decline in abundance and diversity of waterfowl between 1991 and 2017 is substantial, and, while not a direct topic of this MQ deserves attention. Reduction in diversity and abundance of migrant waterfowl are worthy of future examination.

5.1.3.2 Shorebirds

From the nine years of data collected we can confidently conclude that Revelstoke Reach of the ALR is not a high use flyway for shorebirds during migration. Shorebirds were never abundant, with a maximum recorded one-time count of 115 birds. *Calidris* sp. sandpipers were often detected anecdotally using very small habitat patches (residual puddles on roads, very small muddy waterbodies), so their detection was difficult.

5.2 MQ-3 Which habitats and wetland features within the drawdown zone in Revelstoke Reach are utilized by waterbirds and what are their characteristics (e.g., foraging substrate, vegetation, elevation and distance to waters edge)?

Airport Marsh and Cartier Bay were the most utilized wetlands for migratory waterbirds (See Section 5.1), had well-established habitat mapping (Cooper Beauchesne and Associates 2016a), and were the two locations where vegetation sampling occurred under CLBMON-11B-4 (Miller and Hawkes 2014). To address MQ-3, within-wetland habitat use was assessed for these two sites. We elected to focus on dabbling duck associations with CLBMON-11B-4 mapping during periods when reservoir operations did not inundate wetlands (spring). We chose dabbling ducks as they were broadly distributed throughout key wetlands and were most impacted by reservoir operations. Diving duck distribution within the two key wetlands was also considered, but their use of aquatic macrophytes was not examined. The MQ was not addressed for other waterbirds (loons, grebes, cormorants, shorebirds, raptors etc.) due to their low representation or because acquiring suitable data for those species was outside of the scope of this study. For example, there was no survey method in the Terms of Reference for assessing foraging habitat use by raptors.

5.2.1 Aquatic Macrophyte Selection

Water depth is a known significant predictor of dabbling duck density (Colwell and Taft 2000), but depth is also closely associated with macrophyte species, thus it is difficult to disentangle what drives dabbling duck habitat selection. The aquatic macrophytes most commonly associated with dabbling duck density in both Airport Marsh and Cartier Bay are *Potamageton pusillus, Myriophyllum spicatum, Chara sp., Persecaria amphibia*, and *Ceratophyllum demersum* (Appendix 7.4, Appendix 7.20). Each of these macrophytes were detected at plots with duck densities of between 2000 – 3000 bird/hectare (Appendix 7.4). When considering a relative use of duck density in relation to macrophyte availability, other macrophytes emerge as important. The aquatic plants *Sparangium natans*, *Persicaria amphibia*, *Typha latifolia*, *Lysimachia thyrsiflora*, and *Potamogeton pusillus*, and terrestrial moss sp.[3] are all associated with high duck density relative to how common each of those macrophytes are across the study area (Appendix 7.4, Appendix 0).

Whether ducks are targeting these aquatic plants is difficult to know as many of the aquatic features measured studied under CLBMON-11B-4 are correlated, and aquatic vegetation is commonly defined by the depth of water (Appendix 7.4.2). As Colwell and Taft (2000) report, depth is one of the primary drivers for dabbling duck habitat selection so vegetation selection is more likely driven by the depth at which it occurs. Examining the depths at which macrophytes occur, and comparing that to the macrophytes selected by ducks, suggests a propensity for ducks to select macrophytes and mid-level to shallow depths in the study areas (0-75cm deep) (Appendix 7.4.2).

5.2.2 Airport Marsh

Dabbling and diving ducks were distributed throughout the Airport Marsh, but their use was concentrated in areas (Figure 9) in accordance with their guild-specific feeding methods. Dabbling ducks were detected mainly in shallower water near the edges of the marsh, in areas dominated by aquatic macrophytes which flourish at moderate depths (less than 100 cm deep - Appendix 7.4.2). Higher dabbling duck density is associated with the

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[3] Moss is present along the shoreline at Cartier Bay, and while not an aquatic macrophyte, it forms a low mat of vegetation which ducks rest and preen on.

macrophytes *Myriophyllum spicatum*, *Potamageton natans*, *Potamageton pusilus*, and *Chara* sp. (Appendix 7.4.2). These macrophytes are widely distributed and represent four of the five most common macrophytes among CLBMON-11B-4 plots (Miller and Hawkes 2014).

Diving ducks were more evenly distributed, but their use peaked in areas of deeper, more open water. This selection of habitat based on feeding habits is consistent with results produced by other studies (Colwell and Taft 2000, Isola et al. 2000).

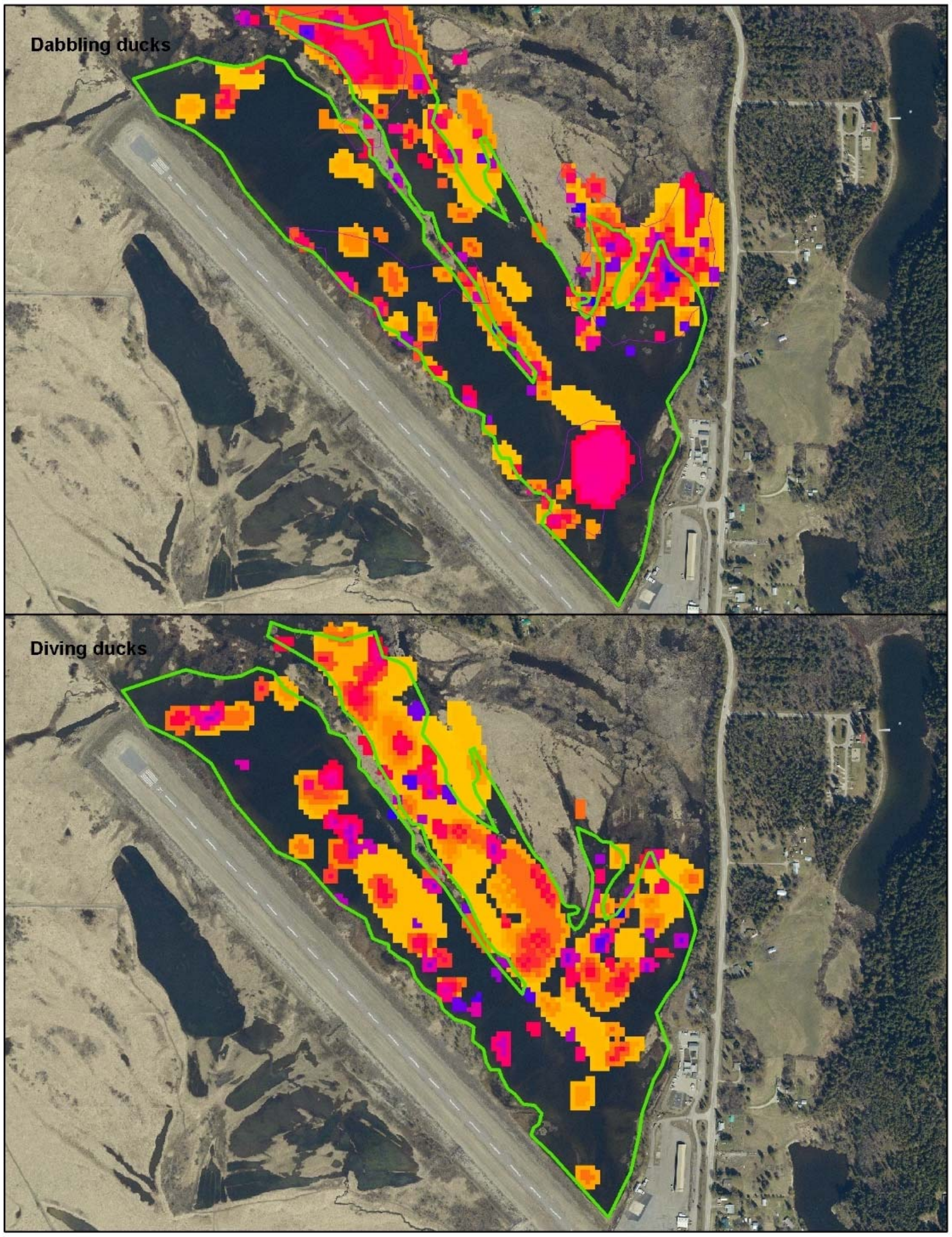

Figure 9: Distribution of dabbling (top panel) and diving (bottom panel) ducks in Airport Marsh. Darker colours represent high use. Dabbling duck density ranges from 0 - 2488 birds/hectare, diving duck density ranges from 0 – 2626 birds/hectare.

5.2.3 Cartier Bay

The Cartier Bay wetland is very low in the drawdown zone (433.5 m) and any aquatic vegetation able to persist there must be able to withstand extended periods of inundation. CLBMON-11B4 describes only 10 plant species growing there (compared to 35 species in Airport Marsh), but 90% of plant species growing in Cartier Bay are aquatic macrophytes (Miller and Hawkes 2014). The most common macrophytes with high associated duck densities in Cartier Bay are *Ceratophyllum demersum*, *Potamogeton pusillus*, *Chara* sp., and *Myriophyllum spicatum*, a similar species assemblage to Airport Marsh.

The wetted area of the Cartier Bay oxbow becomes progressively deeper moving from north (~50 cm deep) to south to where it eventually turns to the west (< 2 m deep) to meet the old Arrowhead rail bed. This distribution of depths is reflected in the use by the two guilds of waterbirds (Appendix 7.16). While dabbling ducks were distributed throughout the wetted area of Cartier Bay, the highest concentrations occurred at the shallow northern end and along the edges, reflecting the shallow depths at which most macrophytes grow (Appendix 7.4). Diving ducks were notably concentrated in the deepest areas of this wetland.

5.2.4 Effects, Challenges, and Opportunities

Improvements in the representation of waterbird mapping from 2011 - 2013 played a role in introducing error into estimations of habitat use. In 2011, observers tended to draw larger polygons, capturing more birds. As these surveys continued in 2012 and 2013, greater effort was placed on accuracy and resolution of the mapped locations, which were used to create a raster layer of duck density. This change in mapping resolution means that fewer raster cells with density values will fall on vegetation plots. Effectively, the extent of use by waterfowl was reduced in 2012 and 2013. This change in mapping resolution could easily be interpreted as lower densities of birds using habitat as the years progressed, but this is simply an artifact of data recording. Little can be done to improve these results at this point without more detailed spatial mapping of aquatic vegetation distribution in Airport Marsh and Cartier Bay. The habitat map generated by CBA (2016) is effective for associating broad habitat values with waterbird densities, but it is not detailed enough for specific vegetation associations.

While much is known about the selection of depth gradients by dabbling ducks (Colwell and Taft 2000, Isola et al. 2000), the results of this analysis help to inform which aquatic macrophytes are selected by ducks in the Arrow Lakes Reservoir. Although this information is a high-level assessment of habitat selection, the results can be used to inform revegetation and physical works projects proposed for the area. A more extensive data analysis likely would produce greater resolution, and better understanding of how the different variables collected under CLBMON-11B-4 influence duck density and distribution.

5.3 MQ-4 What is the annual variation in summer productivity (reproduction) of waterbirds in Revelstoke Reach and do indices of waterbird productivity vary spatially (e.g., are there areas of higher waterbird productivity)?

5.3.1 Annual variation in brood detection

Nine waterfowl species were observed with broods (Appendix 7.5); six were commonly detected with broods annually (Canada Goose, American Wigeon, Mallard, Pied-billed Grebe, Wood Duck, and Common Merganser).

Canada Geese accounted for 67% of all broods detected during the course of the study; thus, they were analyzed separately from other broods (Appendix 7.5). The number of Canada Goose broods detected on each survey ranged from 0 to 18 (Table 5-1). Annually, the fewest maximum number of broods of Canada Geese detected was two broods in 2015.

Omitting Canada Geese, the annual maximum number of brood detections per survey ranged from 1 to 10 (Table 5-1), and the most common species detected with broods were American Wigeon (36%) and Mallard (29%). Annually, the fewest waterfowl brood detections was two broods in 2013.

Table 5-1: Annual variation in waterbird brood detections. Detections represent the minimum and maximum number of detections on a given survey within each year. Year 1 (2008) was excluded due to incomplete data.

Year	Maximum number of waterfowl broods excluding Canada Goose	Maximum number of Canada Goose broods
2009	10	18
2010	7	9
2011	4	14
2012	2	6
2013	1	8
2014	2	7
2015	8	2
2016	2	10
2017	3	16

Interpretation of the above variability must be made with considerable caution (see Section 5.3.5). For example, we do not believe that the low numbers of Canada Goose broods observed in 2015 reflect low productivity. 2015 was a year when reservoir elevations remained very low, and their favoured brood-rearing habitat (flooded grass) was not available in the monitoring area. During aerial surveys we observed large congregations of Canada Goose broods outside of the brood monitoring area in the southern parts of Revelstoke Reach. We strongly believe that the Canada Goose broods emigrated from the brood monitoring area prior to the 2015 brood monitoring field work (Cooper Beauchesne and Associates 2016a). Canada Goose brood emergence mostly occurred prior to survey timing, so only the last broods were observed as they migrated south to the flooded grasslands near Catherwood and Hall's Landing (Figure 1).

5.3.2 Spatial variation in brood detection

Broods were detected throughout the monitored study area, but differentially among the monitored wetlands. Excluding Canada Goose, broods were most commonly observed in Airport Marsh (26%) and Downie Marsh (23%) (Figure 33, Appendix 7.5). Montana Bay and Cartier Bay had similar usage (14% and 13%). When Canada Geese were included in these counts, Montana Bay became the most highly used wetland for brood rearing, with 27% of all detections occurring there. Cartier Bay was the next most used wetland (21%), followed by Airport Marsh (17%). As noted above, Hall's Landing and Catherwood were also known to be important brood-rearing habitats for Canada Goose.

Productivity as a function of wetland is difficult to quantify at higher reservoir levels as flooded habitat facilitates easy travel between wetlands, and reservoir elevations affect detectability. However, for the very youngest broods of species with a life history which exposes them to nest flooding, Downie Marsh emerges as the most important wetland for successful brood rearing, with 50% of very young brood detections (Figure 10, Appendix 7.5). No young broods were observed in Montana Bay, despite 14 nests successfully fledging young at that wetland during the study (Figure 10).

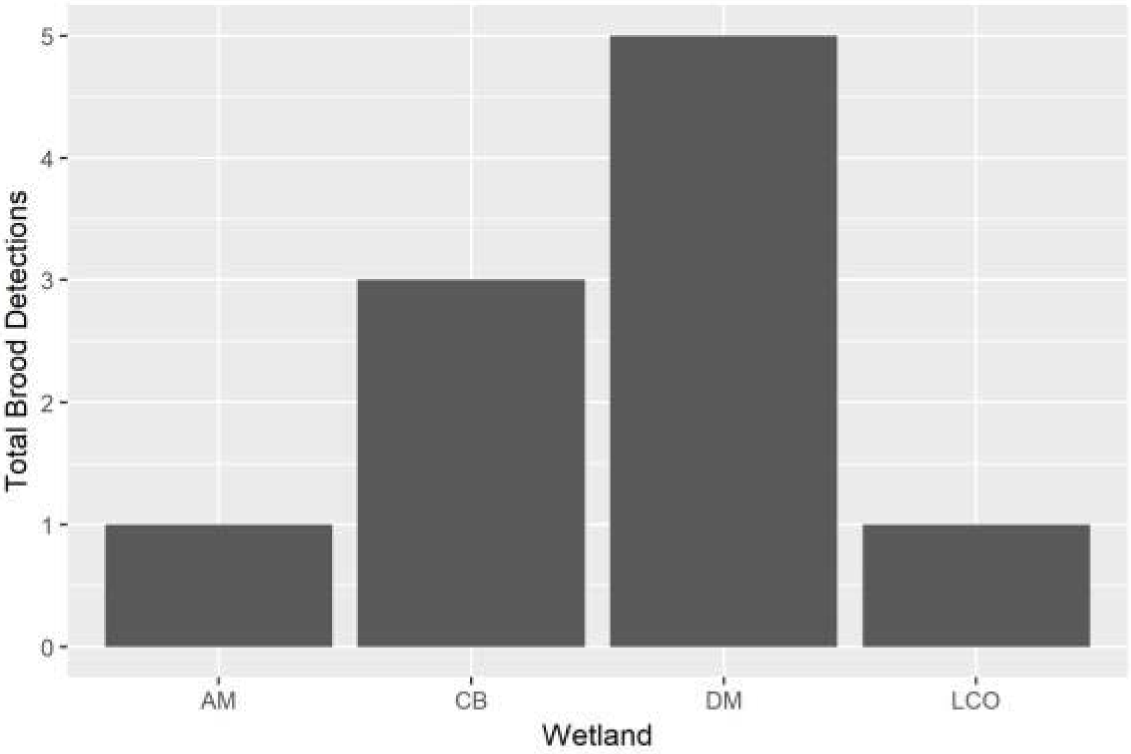

Figure 10: Brood detections by wetland for very young broods (age 1a as per Gollop and Marshall (1954)).

The reason for the lack of detections of young broods in Montana Bay is unclear. The rate of nest depredation is relatively elevated at this site (Table 5-2), which may have relevance. Montana Bay nesting habitat is comprised of floating peat islands which serve as a terrestrial refuge during high reservoir levels. Results from CLBMON-36 show that birds will move to these floating islands as all other terrestrial habitat becomes inundated (Craig and Gill 2020). It is possible that predators may also be congregating on these floating islands during times when broods are emerging, thus increasing the predation rate.

Table 5-2: Data from CLBMON-36 illustrate the difference in nest outcomes between Montana Bay and all other monitored sites with waterfowl nests (Craig et al. 2018). Number of known successful waterfowl nest outcomes as a proportion of total outcomes for Montana Bay and for all other areas.

Area	Outcome	Total Outcomes
All Other Sites	Predation	35
	Successful	39
	Proportion Successful	**53%**
Montana Bay	Predation	24
	Successful	14
	Proportion Successful	**37%**

When all waterbirds, including Canada Goose and other species not at risk of flooding, are included, the largest proportion of very young broods was again detected at Downie Marsh, followed by Cartier Bay, and then Montana Bay (Appendix 7.23).

Given its frequent use by people and despite the occasional occurrence of domestic dogs running off leash at this site, Downie Marsh had a surprisingly high proportion of brood detections, and appears to function as an important brood-rearing area (Figure 10). It may be that this wetland is a relatively important breeding area for waterbirds, or it may be that detectability of broods is higher at this wetland than at the other wetlands because of the close proximity of the wetland to the viewing station, and lack of concealing vegetation compared to other wetlands. Given the diversity of habitat surrounding Downie Marsh, it is probably the former statement, and that this site provides suitable nesting habitat for waterbirds.

Airport Marsh (438 m ASL) is inundated latest of all the wetlands, which likely contributes to the importance of this wetland as nesting and brood-rearing habitat, especially for early-nesting waterfowl. While fewer young broods were detected at this wetland than at Downie Marsh, results from CLBMON-36 reveal that Airport Marsh provides nesting habitat for many of the waterbirds breeding in the study area (Craig and Gill 2020). Canada Goose, American Wigeon, Mallard, Common Loon, and Pied-billed Grebe are known to nest in Airport Marsh, and broods of all but Common Loon have been observed there (Bird and van Oort 2015). It's likely that the complexity of emergent vegetation contributes to a low detection rate for broods at this site.

5.3.3 Annual and spatial variation in Bald Eagle and Osprey Productivity

In Revelstoke Reach forty-three Bald Eagle and Osprey nest locations were monitored, with 162 nest outcomes determined over the course of the study (Figure 11). Bald Eagles were less abundant (16 nest locations) but appeared to be more resilient breeders compared with Osprey; they had nest failures in only five of the ten years of monitoring and had a mean success rate of 75%. In contrast, Osprey nest failures occurred annually, and their mean success rate of 45%.

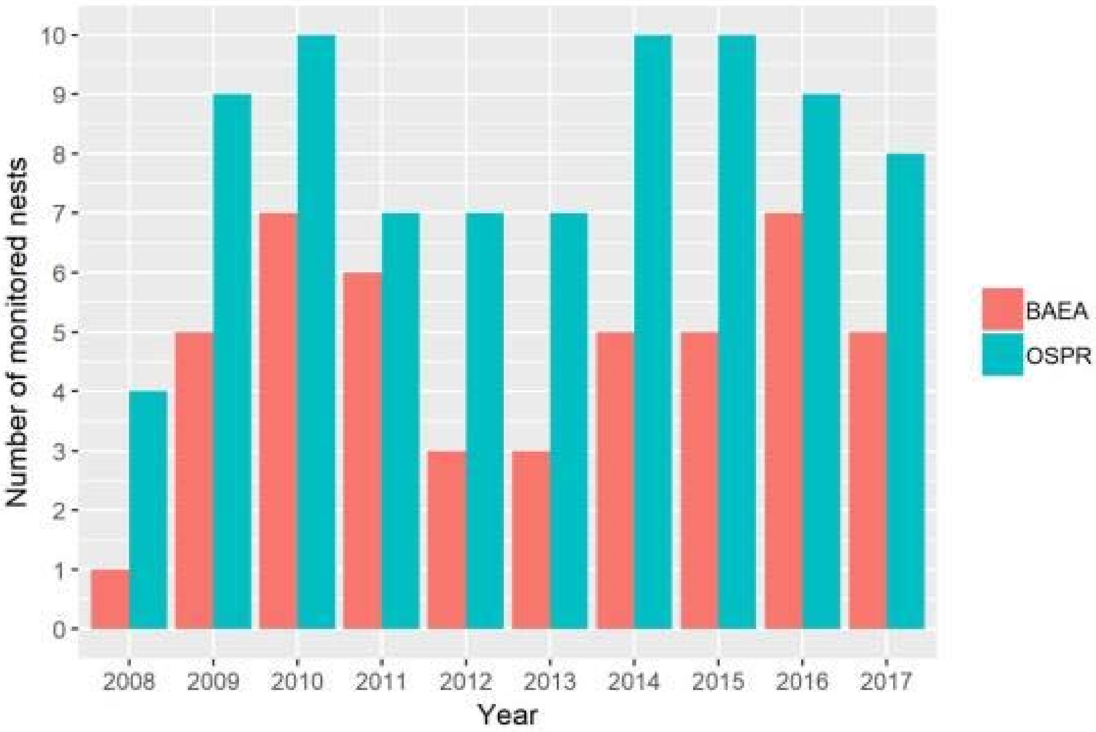

Figure 11: The number of active Bald Eagle and Osprey nests monitored in Revelstoke Reach each year. In 2014 we expanded our study area to include Beaton Arm, to the south of Revelstoke Reach, however, results from those nests are not presented here.

The total number of young fledged annually for Bald Eagle varied from 3 to 12 with 2010 and 2016 having the greatest number of young fledged, and 2012 having the fewest number of fledged young (Appendix 7.27). Osprey were more susceptible to seasonal influences (examined in MQ-7), and had fewer successful nests and slightly more annual variability than Bald Eagles in numbers of fledged young. In 2012, only two young were fledged, and, in 2015, 13 young were fledged. In 2017, a short, but violent windstorm destroyed several active nests, as well nest locations that were known but unused that year. Despite favourable weather conditions in 2017, no young were fledged from nests in Revelstoke Reach.

Spatially, Bald Eagle and Osprey nests were distributed throughout Revelstoke Reach, but the majority of nests of both species were on the west side of the valley (Appendix 7.29). Differences in nesting on either side of the valley could be related to proximity to foraging habitat, differences in forest stand age/characteristics, or potentially due to differences in nest survival (e.g., exposure to prevailing winds). However, even though most nests were situated on the west side of the reservoir, more young per nest were fledged from nests on the east shore (Figure 12).

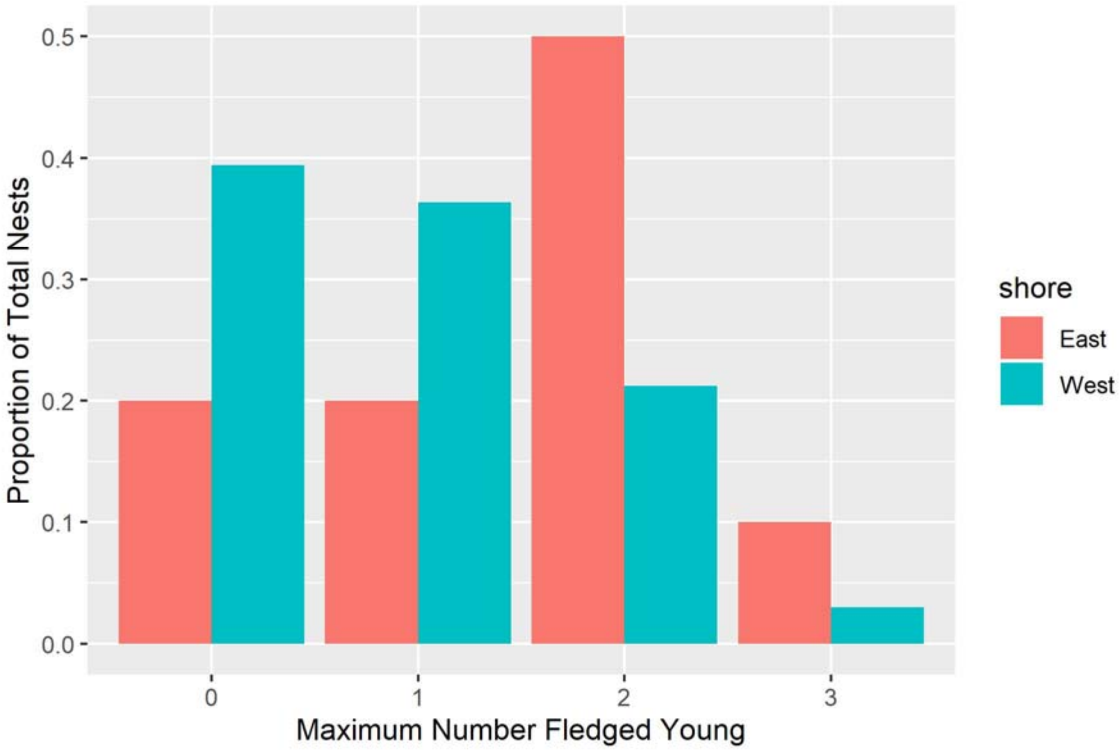

Figure 12: The proportion of nests on each shore plotted against the maximum number of young fledged. Each shore category on the x axis adds to 1.

5.3.4 Annual and spatial variation in Short-eared Owl and Northern Harrier Productivity

The nesting population of Short-eared Owl and Northern Harrier was very small and irruptive within the study area. During the course of the study, Short-eared Owls only nested in two years with three pairs suspected of nesting in 2010 (1 nest found), and two pairs nesting 2016 (4 nests found). Prior to this study, there was no indication that more than one nesting pair was ever present (Boulanger et al. 2002, Jarvis 2003). The five nests found during CLBMON-40 all failed (See Section 5.6.3). Three Northern Harrier nests were found during this study; one in 2014, and two in 2016. Only one Northern Harrier nest was successful (2016).

Prior to this study, a suspected Short-eared Owl nest, reported in 2001, may have been successful (Boulanger et al. 2002, Jarvis 2003, 2006). In 2002 a breeding pair was observed, and, although the nest was not found, it surely failed as the water levels flooded habitat (Jarvis 2003). The two Short-eared Owl nests in 2016 that were established following nest flooding at lower elevations were presumed to be replacement nests, positioned at higher elevations than the other three nests previously recorded.

Short-eared Owl and Northern Harrier select open habitats including prairie, pasture, coastal grasslands, heath, moorlands, marshes, bogs, shrub-steppe, tundra, grassy dunes, and agricultural areas (Campbell et al. 1990, Wiggins et al. 2006). The mixed grass and shrub/savannah habitat of the drawdown zone of Revelstoke Reach mimic these natural habitats at low water levels. Nests were located in the expansive grassland west of the airport, near the point at the northern edge of Montana Bay, and at 12 Mile (Appendix

7.26). Habitat in other parts of the study area are similar to these nesting sites, but no evidence of nesting was found elsewhere.

5.3.5 Effects, Challenges, and Opportunities

Brood surveys function well as an index of waterfowl productivity, but there are challenges with this technique in this study. This method is particularly powerful for tracking productivity over time at particular sites, but this benefit is reduced by reservoir operations, which promotes movement of broods in and out of wetlands, and which alters detectability. It is possible and even likely that when tall grass habitat becomes flooded by the reservoir, for example when the reservoir is at 435 m ASL, broods might not be detected because they could be hidden within areas of flooded grass. For this reason, results gleaned from brood surveys should be interpreted with caution.

Previous physical works projects and nest box installations (CLBWORKS-30A) have either stabilized important brood rearing habitat (replaced box culvert at Cartier Bay), or supplemented existing nesting habitat (Kellner 2013, Watson Engineering 2016). Further nest box monitoring, or physical works projects may further improve nesting opportunities for waterbirds as long as these features are considered in the context of reservoir operations.

Finding nests of Short-eared Owl and Northern Harrier was not planned-for in CLBMON-40, and these nests are very challenging to find. As noted above, some nesting attempts were not confirmed, but adult behaviour suggested nesting was initiated, thus the estimates made by counting numbers of pairs is likely to be accurate.

The infrequent selection of the study area for nesting by Short-eared Owl and Northern Harrier means that it is relatively challenging to study patterns of habitat use. Any future interest in tracking productivity and habitat use by these species should consider a very long on-going monitoring effort.

5.4 MQ-5 Which waterbird species have the greatest exposure to being highly impacted by reservoir operations?

To answer this MQ we drew from data and analysis conducted to answer other MQ's (Sections 5.1, 5.2, 5.3, 5.5, and 5.6). We discuss in general terms the species and groups of species which are impacted by reservoir operations at different life stages. In addition, a list of shorebirds and waterbirds using habitat in the drawdown zone is compiled in Appendix 7.25.

It is beyond the scope of this project to ascertain population-level impacts associated with reservoir operations, but we make the assumption that widespread impacts to breeding productivity have more serious ramifications for waterbirds, compared with impacts that alter migratory stop-over habitat. One reason for making this assumption is that migrant birds are likely accustomed to variable habitat conditions, and are more able to rapidly respond to changing conditions; by contrast, nesting birds commit to habitats for an entire breeding season, and these decisions could be poorly informed when considering breeding in unnatural habitats such as the reservoir drawdown zone. There is no evidence and little concern that migrant bird survival is impacted by reservoir operations, and considerable evidence and concern that reproductive success is impacted. Under this rationale, addressing this MQ focusses largely on identifying which species are most vulnerable to impacts to their reproductive success.

5.4.1 Shorebirds

Among shorebirds, Killdeer and Spotted Sandpiper see the greatest impact from reservoir operations as they are the most numerous breeding species in the region, and they consistently nest in the drawdown zone, often at relatively low elevations (Craig and Gill 2020). From data collected under CLBMON-36, 9.3% of Killdeer nests and 16% of Spotted Sandpiper nests with known fates were destroyed from reservoir operations (Appendix 7.24). The loss of Killdeer nests to reservoir operations is lower because of their earlier nesting phenology (first broods often hatch by June 15th; Cooper Beauchesne and Associates 2018). Spotted Sandpipers nest higher in the drawdown zone compared with Killdeer, but the average date for Spotted Sandpiper nest completion is almost a month later (Craig and Gill 2020).

Wilson's Snipe were also known to commonly nest in the drawdown zone in certain locations. Snipe nests located and monitored under CLBMON-36 were predominantly found on the floating peat island habitat of Montana Bay (Cooper Beauchesne and Associates 2016a). Of all Wilson's Snipe nests monitored under CLBMON-36, 76% come from two monitored plots in this habitat, and the timing of these nests suggest they were likely second attempts at nesting, suggesting failure of the initial nest (Craig and Gill 2020). It is unclear why more nests from this species were not detected outside of this key area, but their specific habitat requirements for nesting (Tuck 1972) may limit them to very few suitable locations in Revelstoke Reach.

5.4.2 Waterfowl

All ground-nesting waterfowl are potentially susceptible to nest flooding, however nest timing varies among species, and this is an important predictor of nest flooding (Craig and Gill 2020).

Among waterfowl species nesting in Revelstoke Reach, Canada Goose, Wood Duck and Common Merganser are not vulnerable to nest flooding due to their nest placement, and timing (Craig and Gill 2020). Most ground-nesting waterfowl which nested in the study area: American Wigeon, Mallard, Blue-winged Teal, Green-winged Teal, Cinnamon Teal, Northern Shoveler and Ring-necked Duck have nest timing and habitat selection (Hepp and Bellrose 1995, Mallory and Metz 1999, Mowbray et al. 2002) making them vulnerable to nest flooding. These species nest throughout the study area and compose 13% of all ground nests monitored under CLBMON-36 (Craig and Gill 2020 p. 36). Reservoir impacts to the nests of these species varies, but the overall loss of monitored waterfowl nests to reservoir operations is 15% (Appendix 7.8). Nests of American Wigeon had the highest proportion lost to reservoir operations, with 16% of them flooding (six of 38 nests). However, Mallard lost the most nests (nine of 62). Impacts to ground-nesting species are covered in detail in the final report for CLBMON-36 (Craig and Gill 2020 p. 36).

5.4.3 Raptors

In terms of the likelihood of nest flooding, Short-eared Owl and Northern Harrier are likely the two waterbird species most-affected by reservoir operations. Both species are expected to have very low chances of nesting success, and the potential for nest flooding is much greater than all other waterbirds; this is due to their nesting at relatively low elevations and the long period of time from egg-laying to fledging of young. The impacts of reservoir operations are discussed in more detail in MQ-7. Neither species is affected often by this impact because their decisions to nest in the drawdown zone are infrequent (Section 4.2.5, Appendix 7.8).

Osprey and to a lesser extent, Bald Eagle, are dependent on nest sites near aquatic habitats for raising young (Anthony and Isaacs 1989, Houghton and Rymon 1994). Studies in the Williston reservoir, in northeast B.C., indicate that reservoir creation may benefit Osprey by increasing the amount of suitable habitat and improving foraging opportunities (Booth et al. 1999, Merkens et al. 1999). Osprey are more directly affected by reservoir operations; this is discussed in MQ-7. A comprehensive analysis of factors affecting Osprey productivity in the study area was completed in 2016, where weather conditions, and reservoir operations were examined to determine how those variables affect productivity (Cooper Beauchesne and Associates 2014, 2016a). Maximum reservoir level during the breeding season was not found to have a significant effect on Osprey productivity, but June rainfall was. This analysis can be found in detail in Cooper Beauchesne and Associates (2016a).

Bald Eagle, with their greater flexibility in diet and nesting locations, were not clearly affected by creation of the Williston reservoir according to those authors, but they suggest that riparian habitat in natural vs. reservoir environments differ, and likely fewer suitable nest trees for Bald Eagle exist in constructed environments. Foraging opportunities for Bald Eagle are not well understood between reservoir mediated and natural environments, but the results of this study suggest there is little effect of reservoir operation on Bald Eagle productivity.

5.4.4 Effects, Challenges, and Opportunities

Without conducting very detailed species-specific studies, quantifying answers to this MQ is not possible. For more detailed account of nest flooding issues for waterbirds, refer to the CLBMON-36 study.

5.5 MQ-6 Do reservoir operations (e.g., daily and maximum monthly water levels) influence the distribution and abundance of waterbirds and shorebirds in Revelstoke Reach?

Seasonal effects overwhelm the reservoir-modulated abundance of waterbirds and shorebirds in the study area (Figure 5). As discussed in MQ-1 (Section 5.1), seasonality is the primary driver of migratory waterbird abundance, and disentangling the effect of reservoir operations on the abundance of waterbirds from broader regional effects is difficult (Appendix 7.11). However, local abundance of waterbirds at key wetlands is clearly influenced by reservoir operations.

Waterbirds are predominantly detected at wetlands during periods of low reservoir levels. These wetlands are scattered throughout the study area, but there are five large and functioning wetlands which account for most of the waterbird use (Downie Marsh, Airport Marsh, Locks Creek Outflow, Montana Bay and Cartier Bay, Figure 1). Of these five, we focused on the four most productive wetlands for addressing this MQ: Airport Marsh, Locks Creek Outflow, Montana Bay, and Cartier Bay. Airport Marsh is a complex of several other wetlands, but we refer here to the main body of the wetland visible from our waterbird monitoring stations.

<u>Waterfowl</u>

For waterfowl, reservoir level has a strong effect on their spatial distribution throughout the study area (Appendix 7.11). At low water levels wetlands account for the majority of waterbird detections. Key wetlands in Revelstoke Reach are all situated between 433 m and 438 m ASL. As the reservoir rises, these wetlands become inundated and habitat heterogeneity throughout the reach decreases until, near full pool, all wetland and terrestrial drawdown zone habitat is essentially converted to littoral habitat (Figure 13).

Figure 13: Revelstoke Reach at high reservoir levels showing inundation of all but the highest, vegetated portions of the drawdown zone.

Aerial survey data indicate that 73% of detections come from wetland habitat at reservoir levels below 434 m ASL, which is just below the level of inundation of Cartier Bay, the wetland with the highest number of detections in the spring (Appendix 7.2). At reservoir levels above 434 m, the proportion of observations from wetland habitat drops to 51% of total waterbird detections (Appendix 7.2; Figure 14).

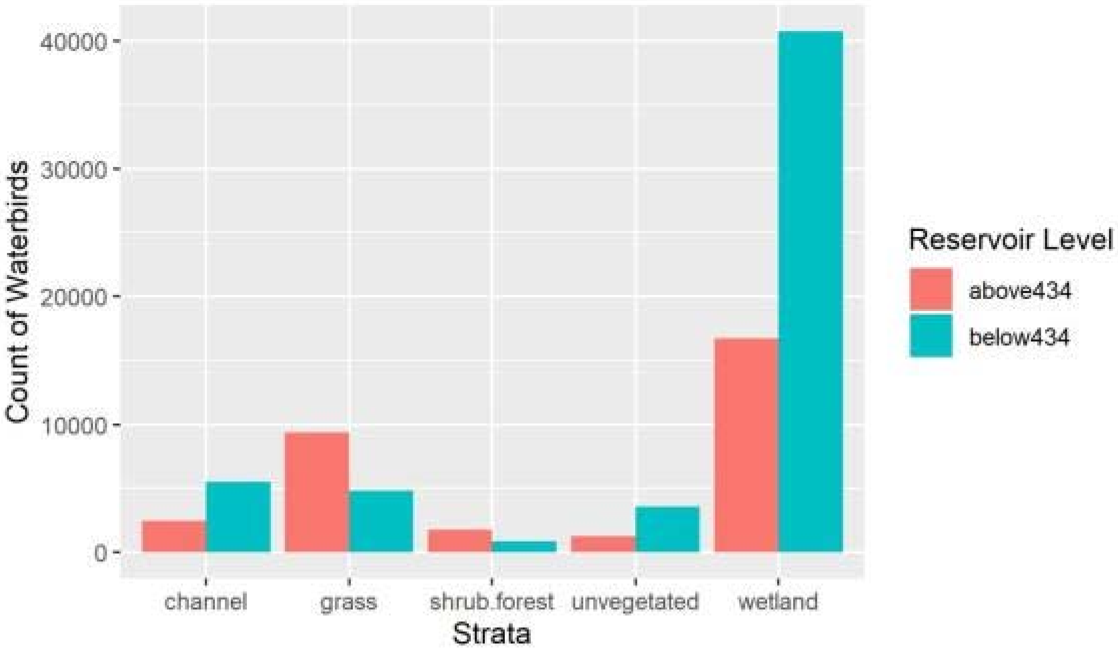

Figure 14: Proportion of waterbirds detected in each habitat type on aerial waterbird surveys. The cutoff of 434 m was used as that is the level at which Cartier Bay becomes inundated by rising reservoir water.

Considering the elevations of these important wetlands which are often flooded during fall migration, we can expand on the trends in Figure 14 to illustrate how patterns of use shift as the reservoir floods these areas. At the lowest reservoir levels, Cartier Bay consistently sees the highest numbers of migratory waterbirds during the migration, but as this wetland becomes inundated, use declines (Figure 15). Birds begin selecting flooded habitat as evidenced in Figure 16, but also move into higher wetlands, or those wetlands with topographical terrestrial features that become inundated (e.g., flooded grasslands at Locks Creek Outflow; Figure 15). Airport Marsh is used consistently at all reservoir levels, and its importance is likely mainly a function of the diversity of habitats found there, but also because it is more insulated from reservoir operations than the other wetlands due to its elevation.

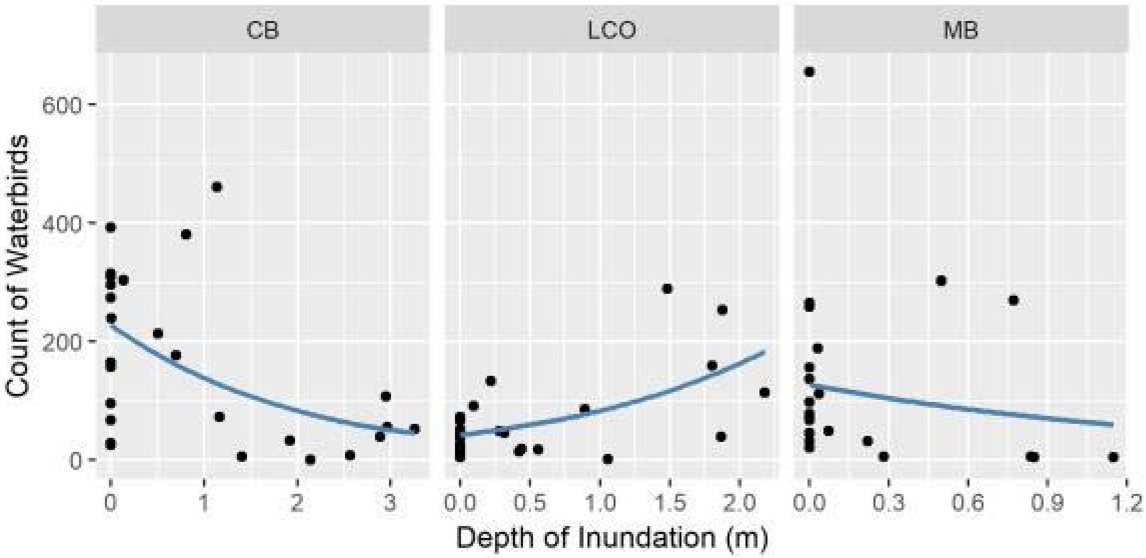

Figure 15: Trends in waterbird use of wetlands during inundation. Points are survey occasions during fall migration. Blue line is a smoothed regression line. CB = Cartier Bay, LCO = Locks Creek Outflow, MB = Montana Bay (Section 7.2).

Wetlands are primarily selected by waterbirds during migration, rather than the main reservoir (Cooper Beauchesne and Associates 2014). As these aquatic habitats become inundated, birds move away from previously preferred habitat and into adjacent, newly-flooded terrestrial habitat. Wetlands are preferentially selected at low water levels and, as the reservoir level rises to flood wetlands, the probability of use by waterbirds declines (Figure 15). As grassland habitat becomes inundated, waterbirds begin to move into areas of shallowly flooded graminoids, but as water depth continues to increase, selection of this habitat decreases (indicated by the rising, then falling blue line in Figure 16). Eventually, as the reservoir passes ~438 m ASL, only shrub and forested habitat remains suitable as foraging habitat for dabbling ducks. For diving birds, water depth is less restrictive for foraging; however, as depth of inundation continues to increase, this guild of waterbird moves out of the wetland habitats as well (Gill and van Oort 2015).

These effects of the reservoir on use of wetland habitat are generally seen during late summer and early fall migration; these habitats are seldom inundated in the spring. By peak migration in October the reservoir has drafted to levels which make available most wetland habitat in the key wetlands.

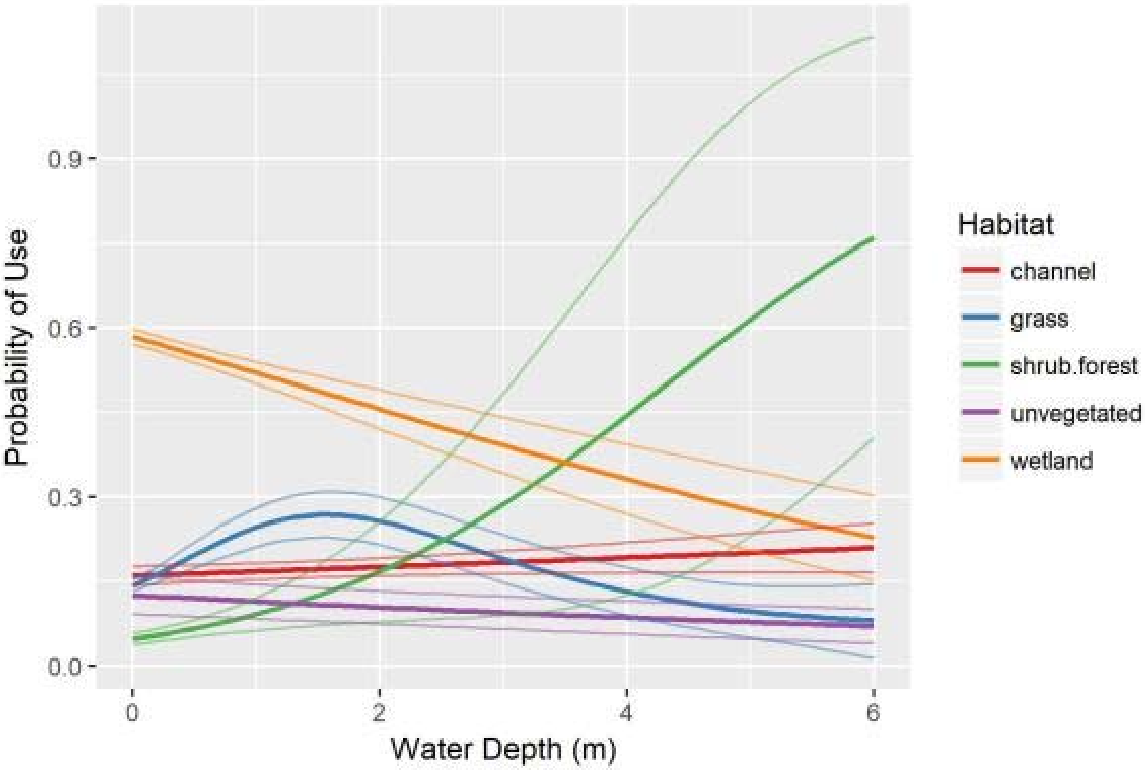

Figure 16: Habitat selection by waterbirds as a function of water depth (adapted from (Cooper Beauchesne and Associates 2013a).

<u>Shorebirds</u>

Evidence that shorebird abundance was influenced by reservoir operations requires statistical analysis so that the variability in shorebird abundance is correctly assigned to the correct causative agent. Analyses were inconclusive, and more work will be required before the effects of reservoir on abundance can be assessed. There were some patterns that suggest a possible interaction (Appendix 7.9), but it was not possible to disentangle the complexities related to the species-specific timing of migration.

There are several methodological challenges to addressing this MQ for shorebirds (Appendix 7.9). One such challenge is that high reservoir levels inundate vegetated areas, concealing shorebirds and limiting them to ephemeral or difficult-to-survey habitats. For this reason, this MQ is discussed from the perspective of abundance and spatial variability at low reservoir levels. Shorebird species diversity is slightly higher at lower reservoir levels, during the earlier part of migration and, as the season progresses, species diversity diminishes (Figure 17). Low reservoir elevations expose mud and sparsely vegetated habitats which provide ideal foraging conditions as long as sufficient prey are available (Figure 18) (Schleppe et al. 2013).

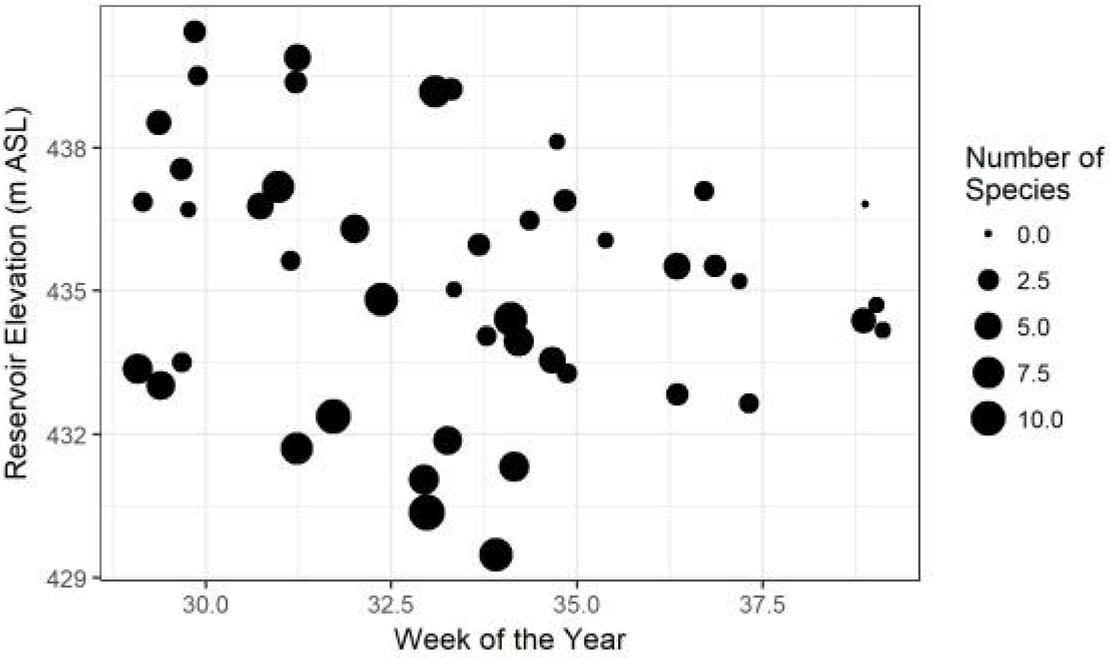

Figure 17: Reservoir level as a function of week of the year during shorebird surveys (Appendix 7.9). Size of each dot represents the number of species observed on each survey occasion.

Figure 18: Low reservoir levels expose unvegetated mud and silt. These mud flats are not part of any of the key wetlands, but this photo illustrates how unvegetated, muddy substrates become available as the reservoir levels recede.

At low reservoir levels shorebird abundance at monitored wetlands was greatest at Cartier Bay, with Locks Creek Outflow having nearly the same number of detected shorebirds (Figure 19). The number of shorebirds at these wetlands is high primarily as a result of flocks of Dowitcher sp. (*Limnodromus* sp.) which arrive late in migration and take advantage of the muddy substrate exposed along this watercourse when reservoir level is low (below 433 m ASL). Figure 19 shows how diversity is highest at Airport West, and lowest at Montana Bay, likely a reflection of the diverse and expansive shallow water habitat at Airport West.

Diversity of shorebird species was highest among those ponds with a higher diversity of water depths and wetland features (Airport West and Machete Ponds), a logical trend given the morphological differences among detected shorebirds, which influence habitat use (Novcic 2016).

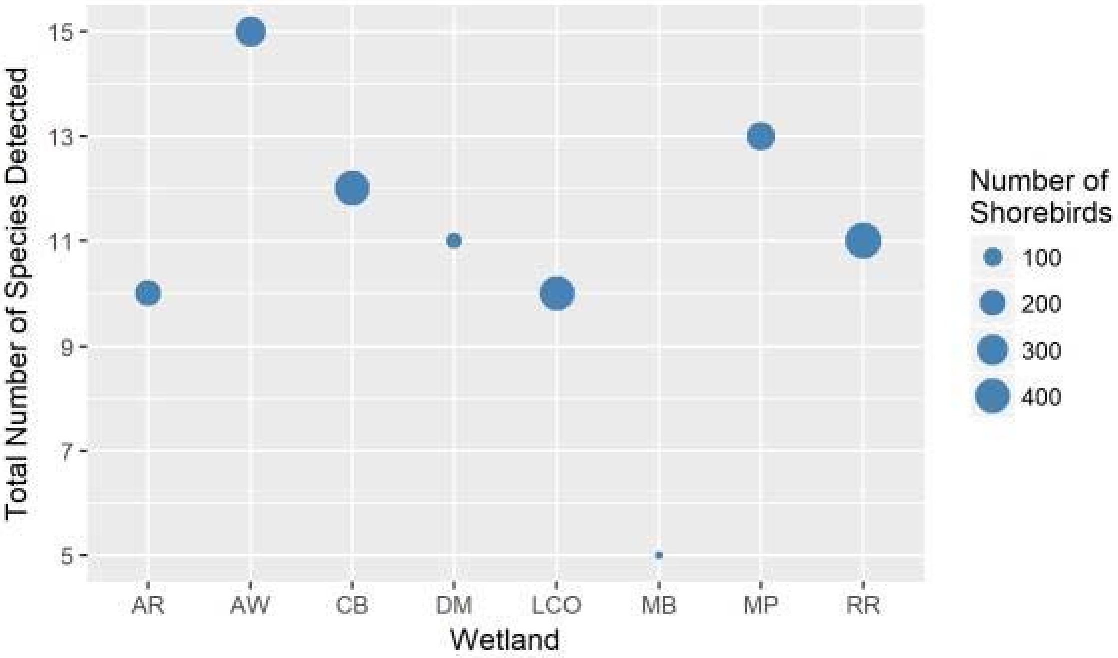

Figure 19: Shorebird diversity and abundance at monitored wetlands. Size of the dot represents the total number of birds detected at these wetlands over the course of the study. AR = Akolkolex River, AW = Airport West, CB = Cartier Bay, DM = Downie Marsh, LCO = Locks Creek Outflow, MB = Montana Bay, MP = Machete Ponds, RR = Revelstoke Reach.

Overall, shorebirds use the study area in low numbers during the fall migration, and their pattern of abundance and diversity appears irruptive, which may reflect broader/external forces acting on shorebird migration, that cannot be accounted for locally. Annual variation in populations, seasonal weather patterns and stopover timing may all contribute to annual variation in abundance and diversity of shorebirds.

Spatially, we understand which habitats are important to shorebirds when the reservoir is low enough to expose muddy, organic substrates. At very high reservoir levels, little suitable habitat is available in the drawdown zone, and this may preclude use by shorebirds during migration. While restricted access to suitable substrates for foraging is the proximate factor for few detections of shorebirds, it is possible that reservoir operations themselves limit the suitability of habitat, even when muddy and organic substrates are exposed. A study of the effects of water level manipulation on of benthic invertebrates in a hydroelectric reservoir in Minnesota showed that artificially fluctuating water levels had a negative effect on the abundance and diversity of invertebrates (McEwen and Butler 2010). Locally, CLBMON-15B has studied benthic invertebrates in Revelstoke Reach and found that the highest abundance exists mid-channel, and in permanently wetted areas of the drawdown zone (Schleppe et al. 2013). Thus, it is conceivable, that even though these muddy substrates are exposed, they may not host sufficient invertebrates to provide high value foraging habitat for shorebirds.

5.5.1 Effects, Challenges, and Opportunities

A fairly strong conclusion can be made that reservoir operations influence the distribution of waterbirds in Revelstoke Reach, however, it remains unclear if waterbird abundance is affected. During the breeding season, a strong case can be made that abundance of certain waterbirds is influenced by reservoir elevation; for example, at full pool, breeding Short-eared Owls vacate the area as all of their foraging habitat (and nests) is submerged. However, there are several challenges to determining how abundance is affected by reservoir elevation during migrations; these include: (1) controlling for natural seasonal variation in abundance; (2) controlling for external effects (e.g., year-effects, weather); and perhaps most challenging of all, (3) controlling for changing detectability of waterbirds as reservoir elevations change. The abundance of shorebirds in response to reservoir levels is particularly difficult to ascertain as they occur in low numbers, and their appearance is unpredictable. In addition, very small suitable habitat patches exist at most reservoir levels, and the logistical challenges of surveying representative habitat makes it likely that birds were missed.

5.6 MQ-7 To what extent do water levels in Arrow Lakes Reservoir influence indices of waterbird productivity in Revelstoke Reach?

There are likely no mechanisms that can be as clearly linked to reservoir operations, and undoubtedly none that are as impactful to waterbird productivity, as the mechanism of nest flooding. In fact, no other mechanisms of impact were detected during this study. Nest flooding is well-studied under the companion monitoring study CLBMON-36, and this MQ is therefore best addressed under that study. Here we provide some additional data which is unique to CLBMON-40.

5.6.1 Waterfowl Productivity

Reservoir operations had a distinct effect on brood counts among years, where fewer broods were observed in years of higher reservoir elevations (Appendix 7.10). Vulnerable species were those that nest low in the drawdown zone such as Mallard, and American Wigeon (Appendix 7.8). In years when ALR reached near maximum elevation (2008, 2011, 2012, 2013, 2017), or, as in 2016, when the reservoir filled early (maximum ALR water level was 437.2 m on June 13), but did not inundate the very highest elevations, productivity was lowest. In low water years (2009, 2015, 2016) brood detection was generally higher (Appendix 7.10).

Like all other ground-nesting species, inundation of nesting habitat has direct effect on the survival of nests (Craig and Gill 2020), and thus the loss of nests during high years affects the numbers of broods detected. However, in years when the reservoir fills later, or habitat inundation affects only grasslands, there were likely more broods than we detected. The reason for this would be the large increase in flooded terrestrial habitat which provides large areas of cover for broods.

As noted in Appendix 7.10, care must be taken when interpreting brood count data in reservoirs, where habitats and connectivity among habitats change so dramatically across reservoir elevations. The mobile broods can be reared in different habitats and at different locations, depending on reservoir elevation. Additionally, detectability due to differences in vegetative obstruction may depend on reservoir elevation. For these reasons, the brood count method has inherent biases that are near-impossible to account for. Nonetheless, the findings that brood counts decline in years of high water is consistent with findings from CLBMON-36, where a waterfowl were noted to have considerable vulnerability to nest flooding (Appendix 7.8; Cooper Beauchesne and Associates 2018).

5.6.2 Bald Eagle and Osprey Productivity

Bald Eagle and Osprey situate their nests high up in trees or on other structures along the valley bottoms of the Columbia River, and are not at risk of nest flooding.

There is a possibility that reservoir operations affect foraging efficiency for piscivorous raptors. While Bald Eagles have more flexibility in their diet, Osprey are almost obligate fish eaters, with 99% of their diet being comprised of fish (Poole et al. 2002), and position their nests close to water to facilitate better provisioning for their young (Poole et al. 2002). Nests in Revelstoke Reach are situated along each bank of the Upper Arrow Lakes reservoir and, as discussed in MQ-5, productivity varies spatially. Productivity has also been shown to vary with reservoir operations, and June rainfall in previous CLBMON-40 annual reports (Cooper Beauchesne and Associates 2014, 2016a). Variation in annual productivity for Osprey in Revelstoke Reach is detailed in Appendix 7.6. In-depth analysis of Osprey productivity was conducted in Year 8 (2015 - (Cooper Beauchesne and Associates 2016a), and revealed strong negative effects of rainfall in June and maximum annual reservoir elevation on nesting success for Osprey. In 2017 a violent windstorm during the breeding cycle resulted in a high rate of nest failure. While data from 2017 was included in a multi-year analysis, the low rate of success cannot be considered to be a function of precipitation (Figure 20). This analysis is not presented in this report, but methods and results can be found in (Cooper Beauchesne and Associates 2017a).

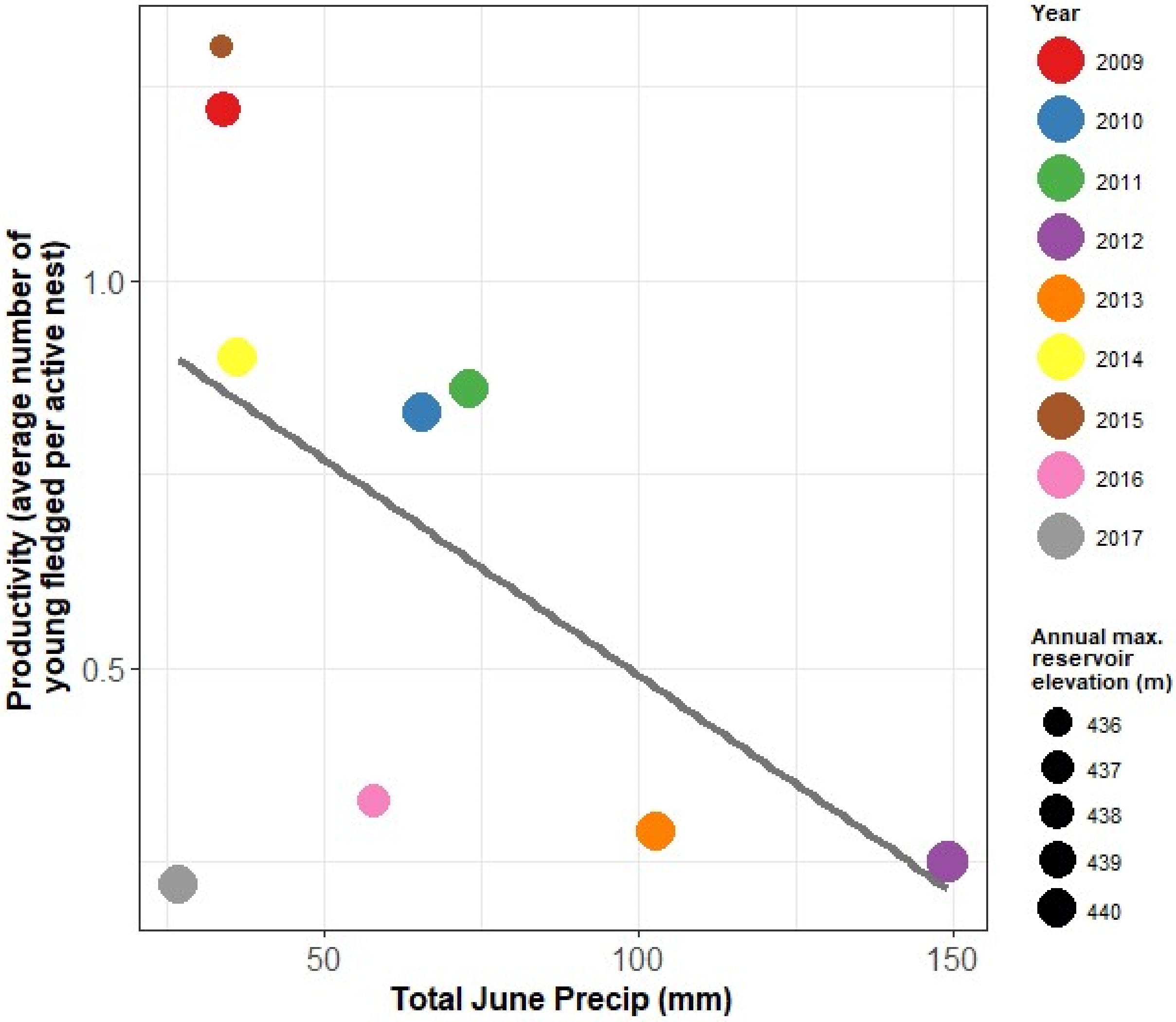

Figure 20: Average number of Osprey young fledged from active nests, plotted against total June precipitation. Maximum reservoir elevation is shown by the size of the dots, larger dots indicate a higher reservoir.

Bald Eagle productivity varied little annually and was not detectably affected by reservoir operations. As stated previously, this may be because of higher flexibility in their diet, or differences in foraging tactics (Merkens et al. 1999, Buehler 2000). Bald Eagles are known predators of waterfowl, and the high reservoir levels which negatively affect Osprey may provide a benefit to Bald Eagles as waterfowl choose flooded vegetation for foraging and security habitat. These flooded habitats provide oblique cover, but not cover from overhead predators.

Bald Eagle seem to be more resilient with regards to these environmental variables affecting their breeding success, and this may be attributed to their more flexible diet (Buehler 2002). Osprey primarily feed and raise young on fish, and changes to the limnetic environment in which they forage may reduce their success.

5.6.3 Short-eared Owl and Northern Harrier Productivity

As early spring migrants, Short-eared Owl and Northern Harrier initiate breeding well before the reservoir has inundated even the lowest margins of the ALR, settling in grassland habitat which is just beginning to green-up. Impacts of reservoir operations on the productivity of Short-eared Owl and Northern Harrier productivity are likely to occur via two inter-related mechanisms: (1) via modulation of food availability, and (2) via modulation of nesting success. In the absence of the latter, the former would be a notable effect, as food availability is likely to control drawdown zone capability to support these species, and also their decisions to nest in the drawdown zone. However, promoting food availability is not favourable for these species, because the nesting phenology and habitat selection of Short-eared Owl and Northern Harrier exposes their nests to a very high risk of nest flooding in most years (Table 5-3) (Cooper Beauchesne and Associates 2016b). A complete analysis of the effects of reservoir operation and climatic factors was conducted in Year 9 of CLBMON-40. Methods and results for that analysis can be found in (Cooper Beauchesne and Associates 2016a).

Table 5-3: Outcomes for all Northern Harrier (NOHA) and Short-eared Owl (SEOW) nests in the Arrow Lakes Reservoir. The fate of the nest in 2010 is listed as 'Reservoir Operations as it would have flooded, but nestlings were removed and raised in a rehabilitation center prior to their release. Termination Date is the date when the nest was first observed to no longer be active.

Termination Date	Species	Nest Outcome	Number Young Fledged
2010-06-22	SEOW	Reservoir operations	0
2014-05-26	NOHA	Abandoned	0
2016-07-06	SEOW	Predation	0
2016-05-30	NOHA	Reservoir operations	0
2016-06-09	SEOW	Reservoir operations	0
2016-06-12	SEOW	Abandoned	0
2016-06-30	NOHA	Successful	3
2016-06-30	SEOW	Predation	0
2016-06-09	SEOW	Reservoir operations	0

Based on data from the five Short-eared Owl nests monitored, a daily nest survival probability of 0.94 was estimated, resulting in nest "success" estimate of ~ 9.4 % over a 50-day nesting period. It seems clear that Short-eared Owls are very unlikely to breed successfully in Revelstoke Reach since reservoir operations flood their nesting habitat during the nesting season virtually every year.

With only five nest records from two years (four of which are from 2016), the sample size is small. Establishing results with statistical significance from these few data is difficult; however, there is likely a biological link between reservoir mediation of prey species and the presence of ground-nesting raptors the following spring (van Oort et al. 2018). Results indicate the level and duration of habitat inundation, as well as winter weather conditions may predict the presence of these species the following spring (van Oort et al. 2018). When reservoir levels are relatively low in summer, vole populations survive and are able to reproduce through the summer and fall, thus are available for Short-eared Owls and Northern Harriers to forage on during the following spring. When reservoir operations flood the entire grassland habitat, most voles are unable to persist, and recruitment back into this habitat is suppressed due to lower reproduction rates in the fall and winter, resulting in fewer prey available the next spring for vole-eating raptors (Negus et al. 1977). When vole numbers are high, these two raptors stay to breed; when vole numbers are low, these species move on and do not breed.

It is likely that variation in annual reservoir operations affects the availability of prey (i.e., the vole population) in the drawdown zone. At full pool, inundation completely eliminates vole habitat and the drawdown zone is not suitable for vole survival. Grassland habitat becomes available again later in the season (e.g., in autumn), during which time voles are once again able to immigrate and disperse into the vacant drawdown zone grasslands. During the remainder of the fall, the vole population in the drawdown zone is expected to grow at a slow rate: vole reproductive capacity is low at this time of year due to reductions in photoperiod and nutritive value of vegetation (Pinter and Negus 1965, Negus et al. 1977); additionally, Negus et al. (1977) report that *Microtus* spp. litters born in the fall do not reproduce until the following spring, further inhibiting repopulation of the drawdown zone habitat. As such, full pool conditions are unlikely to promote an abundant vole resource. By contrast, operations that do not completely inundate grasslands may allow vole populations to build up over a longer time period, and it is therefore theorized that reservoir operations have a significant impact on the food resource of Short-eared Owl and Northern Harrier.

Prior to settlement, raptors that are vole-specialists are known to prospect for sites based on suitable habitat and availability of prey (Phelan and Robertson 1978, Village 1987, Korpimaki and Norrdahl 1991, Poulin et al. 2001). Based on the theory outlined above, it is possible that suitable prey resources are dependent on reservoir operations. Suitable vole abundance is more likely to be realized following a year of low reservoir levels. The corresponding probability of nesting is therefore likely to be reduced following years when the reservoir was filled to capacity and increased following a year of low reservoir levels.

While it is possible for these raptors to nest successfully, and this may have occurred previously (Jarvis 2003), nesting is without doubt, a very risky proposition for Short-eared Owl and Northern Harrier. Suitable nesting habitat in the drawdown zone exists only between 433.7 m and 437.7 m ASL, an elevation band that was partially or fully flooded in every year of the study. This habitat may be flooded starting in late May, with the probability of flooding increasing over time and being higher at lower elevations earlier in the year (Appendix 7.28). Dates of habitat flooding correspond with the early- to mid-nesting season for Short-eared Owl and Northern Harrier.

The earliest known date of nest initiation for Short-eared Owl was April 29 (2010), while two other nests (presumed second nesting attempts) had known first egg dates of June 8 and June 13. As reported by van Oort et al. (2016), the mean nest elevation was flooded in 79% of all years by July 2. Nests were found at varying stages; in 2010, the nest was not located until young nestlings were present, while in 2016, all nests were located during the incubation stage. Three of the five Short-eared Owl nests failed due to reservoir flooding[4], the other two nests failed from predation. For Northern Harrier, the nest in 2014 was abandoned and subsequently scavenged, while one nest in 2016 failed due to reservoir operations. One nest in 2016, was successful, fledging three young. This nest was situated relatively high in suitable habitat, and that, combined with a low reservoir in 2016 contributed to successful fledging.

Short-eared Owl and Northern Harrier are highly susceptible to nest failure due to reservoir operations by virtue of their nest placement (low elevations in the drawdown zone) and nesting phenology. Even though nest initiation occurs generally early in the summer, duration of nesting (eggs through fledging of young) is about 50 days, which, under any current reservoir operation regime, puts these species at risk of nest flooding (Campbell et al. 1990).

5.6.4 Effects, Challenges, and Opportunities

Osprey are a species that may benefit from reservoir creation (Merkens et al. 1999), and their populations also appear to be secure (Davidson et al. 2012). The monitoring program, and the abundance of Osprey nests on the Arrow Lakes Reservoir both indicate that Osprey population is robust in this reservoir. If Osprey productivity remains a concern, additional data on Osprey nesting success would improve certainty in the statistical disentangling of the drivers of Osprey productivity (e.g., the impact of rainfall versus reservoir operations). Searching for pre-existing data from elsewhere in the Columbia Mountains (e.g., from Burton, and from Kootenay Lake) could help improve the analysis. Additionally, adding more years of monitoring would help as this would increase the sample size of distinct reservoir operations (an annual effect).

Understanding the impact of reservoir operations on the productivity of ground-nesting waterbirds is probably best approached using by examining nest survival. The CLBMON-36 final report can be reviewed to gain additional information on how reservoir operations affect ground nesting waterbirds. In addition, to better understand nesting decisions by Short-eared Owl and Northern Harrier a study on small mammals and their population response to reservoir operations would likely lead to a better understanding of the mechanisms behind decisions to nest in the drawdown zone.

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[4] One of these three nests had nestlings removed and raised at a rehabilitation facility. That nest is considered ‘failed’ here as it would have flooded before the nestlings were able to evade the rising water.

5.7 MQ-8 Can minor adjustments be made to reservoir operations to minimize the impact on migrating waterbirds or on indices of waterbird productivity?

Arrow Lakes Reservoir is regulated to meet Columbia River Treaty (CRT) obligations, for flood control, and power generation. After operational commitments have been met, there may be potential for residual flexibility in operations that can be optimized to mitigate operational impacts or meet other operational targets. Optimizing flexibility to mitigate impacts to waterbirds will not necessarily be beneficial for fish, recreation, or additional power generation (Hawes et al. 2014, Schwarz 2017), and so it is understood that trade-offs need to be made. We do not attempt to quantify what ‘minor adjustments’ to reservoir operations entail, but we offer suggested guidance for how reservoir operations can be adjusted to most effectively reduce impacts to waterbird productivity or their stop-over habitat, as opportunities arise.

For MQ-5 we concluded that the influence of reservoir operations on waterbird productivity was more impactful than its influence on waterbirds during their fall migration. It follows that the greatest ecological benefit will be gained by making adjustments to benefit productivity in spring and summer; such adjustments can also improve compliance under the Migratory Birds Convention Act and BC Wildlife Act. Enhancing the suitability of migratory stop-over habitat in fall is possible, and also worth considering, but will gain less ecological benefit.

Exposure to nest flooding impacts varies among waterbird species nesting within the drawdown zone. At one end of the spectrum is the Canada Goose with virtually no risk of nest flooding because the species nests very early in the year (when the reservoir is low), has a short nesting cycle (because young are precocial), and nests in the upper elevations of the drawdown zone. Conversely, the Northern Harrier and Short-eared Owl both nest very low in the drawdown zone and have extended nesting cycles (because young are altrical), and therefore have very high probabilities of nest flooding. Most other waterbirds nesting in the area fall between these extremes (see Section 5.4, Appendix 7.8, Appendix 7.28).

Because Short-eared Owl is listed under the Species at Risk Act (SARA) as a species of ‘Special Concern’, this species demands particular attention, despite nesting in low numbers, and infrequently among years (see Section 5.6). Guidelines to manage the reservoir to minimize impacts to the Short-eared Owl were detailed in the Year 9 annual report (Cooper Beauchesne and Associates 2017a). Because the elevational range and timing of nesting for Short-eared Owls was well-understood, guidance to avoid nesting was well-informed. However it was concluded that the guidance to avoid nest-flooding would almost always to require adjustments to operations that likely cannot accommodate hard constraints such as CRT obligations (Cooper Beauchesne and Associates 2017a). As such guidance to avoid nest flooding will generally not fall into the category a ‘minor adjustment’.

A second operational guideline was suggested that was likely to be achievable as a minor adjustment more often. This second guideline was based on the premise that it is never beneficial for Short-eared Owls to nest in the Arrow Lakes drawdown zone, and that nesting should be discouraged. The guidance was based on robust biological reasoning backed by well-studied ecology for this species (Cooper Beauchesne and Associates 2017a), but lacking local empirical evidence. The recommended approach is to reduce food availability which is an important factor determining the locations where Short-eared Owls nest (Phelan and Robertson 1978, Village 1987, Korpimaki and Norrdahl 1991, Poulin et al. 2001). The analysis performed in Year 9 suggested that vole populations might be reduced if the reservoir elevation exceeds 437.7 m asl each year prior to winter (Cooper Beauchesne and Associates 2017a).

Adjustments made for Short-eared Owl will also serve the Northern Harrier well. For all other waterbird species, we recommend advice derived for all nesting birds produced under CLBMON-36: any ability to delay the rising limb of the hydrograph (i.e., delay timing of spring draw) will have a large benefit for nesting birds (Craig and Gill 2020). Due to the sheer numbers of birds nesting in Revelstoke Reach, including many waterbirds, this guidance is exceptionally beneficial for improving avian productivity. It is notable that during the CLBMON-36 and CLBMON-40 studies, the opposite trend was apparent; reservoir storage was advanced compared with historic operations. Reversing this trend will greatly reduce nest-flooding impacts.

Regarding stop-over or staging habitat for waterbirds during the fall, operations that allow Cartier Bay to be minimally flooded will make the single most important wetland available for waterbird usage. This should be a possible adjustment in some years, but generally will entail a rather large adjustment which is likely not possible (Figure 21). Over the course of this study, the reservoir was below 433 m during fall migration in only two of 10 years (2015, 2016, Figure 21). Maintaining the reservoir below 433 m during fall migration would likely require larger operational changes than could be considered 'minor adjustment' and thus is not considered.

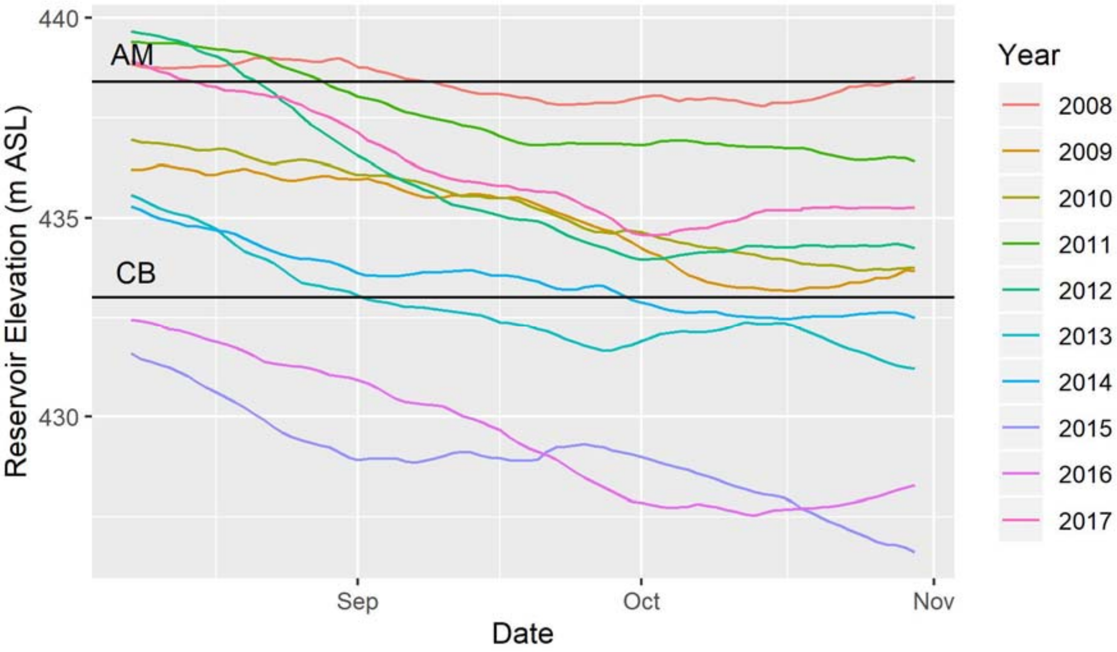

Figure 21: Reservoir levels during the study period (2008-2017) during the period of soft constraints for waterbirds. The black, horizontal line labeled 'AM' is the soft constraint target for migrating birds (438.4 m ASL). The black horizontal labeled 'CB' is the elevation of Cartier Bay (433 m ASL), the most important wetland for migrating waterfowl.

5.7.1 Effects, Challenges, and Opportunities

What constitutes a 'minor change' in reservoir operations has not been defined, so guidance is provided must be used on a case by case basis among years. Additionally, individuals will differ in values, and prioritization of objectives. In the scope of this MQ, we believe that the most applicable and ecologically beneficial guidance (i.e., greatest effect size) is the general delay of spring storage to reduce nest flooding, followed by the goal of flooding grassland habitat annually to reduce vole populations and prevent Short-eared Owl nesting.

Additional long-term monitoring of Short-eared Owl nesting is necessary before a linkage between nesting and reservoir operations can be statistically varified. Monitoring vole populations would also be beneficial to better understand and model how reservoir operations are linked to the probability of this SARA-listed species nesting in the drawdown zone.

5.8 MQ-9 Can physical works be designed to mitigate any adverse impacts on migrating waterbirds or on indices of waterbird productivity resulting from reservoir operations?

Opportunities for wildlife physical works projects exist throughout Revelstoke Reach. After 10 years of study we believe physical works projects can be created which benefit all wildlife using the drawdown zone.

An important consideration with placement, and construction of WPW's is to not create conditions which cause an ecological trap (e.g., encouraging use for nesting only to have nests flooded by reservoir operations). Creation of low elevation wetlands for migratory birds, or high elevation wetlands which are protected from reservoir operations, would be most desirable. In addition, large floating islands may have an application in the drawdown zone to provide habitat which moves dynamically with changes in reservoir elevation. Floating artificial islands have been used in the study area and the Whatshan Reservoir to improve productivity of nesting Common Loon (Kellner et al. 2013, Kellner 2015). In Revelstoke Reach study area, a very large natural floating island in Montana Bay (Cooper Beauchesne and Associates 2012) provides refuge from flooded habitat for nesting birds, beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), and river otter (*Lontra canadensis*), as well as other small mammals.

Mounded, artificial islands are not a new concept for habitat compensation, and have been shown to be effective at increasing waterfowl productivity (Brenner and Mondok 1979, Giroux 1981). Construction of mounded islands in the study area has been proposed (Golder Associates 2009 p. 29) near the mouth of Cartier Bay, at the Columbia River. These WPW's have potential to increase high elevation habitat, as well as low elevation wetlands, if mounded islands are situated adjacent to where the material is excavated from. Ignoring the logistical challenges of such features, the primary consideration is that mounded habitat extends above the full pool mark to limit nest mortality during the breeding season. Vegetated mounds could provide forage, security and resting opportunities for both waterbirds and shorebirds. Unvegetated mounds could provide forage and resting opportunities, as well as nesting opportunities for Spotted Sandpiper and Killdeer.

Dyking of Airport Marsh to insulate it from reservoir elevations below 438 m was considered in the Year 7 CLBMON-36 report (Cooper Beauchesne and Associates 2016c). Analysis of nesting data revealed that a dyke protecting the wetland habitat could potentially reduce nest losses due to inundation by 18% (Cooper Beauchesne and Associates 2016c).

Potential WPW sites are listed in Appendix 7.31, with sites mapped in Appendix 7.32.

Any physical works project should consider how a modified environment could impact the currently functioning ecosystem in the drawdown zone. Several of the key wetlands were the by-product of historic construction (e.g. Arrowhead railway) (C. English pers. comm.).

Over time, these features impounded ponds and streams and, with the subsequent flooding and reversion from an agricultural landscape to a managed waterbody, created wetlands. Bulldozers were used to raise the level of the airport runway, prior to flooding, creating the ponds at Airport West, and deepening Airport Marsh. Water impoundment by the railbed at Cartier Bay and Airport Marsh has created valuable wetland habitat within impounded areas. Machete Island likely exists because it was originally the site of a pole yard, which would have produced ample compost to raise the land and promote growth of cottonwood trees. While artificial, and seasonally flooded, at low reservoir levels many of these habitats function well ecologically.

While these historic changes to the landscape were a fortunate accident, they modified a terrestrial landscape, not currently functioning wetlands. New physical works have the potential to have detrimental effects and, any proposed works should be critically assessed for how they might modify existing habitat and affect other species of wildlife and fish.

Any physical works projects should consider the findings of other WLR projects. Physical works which create habitat for other fish or wildlife species within the annual high-water mark have the potential to create an ecological trap for nesting waterbirds unless their design considers specific waterbird habitat requirements and seasonality of use (Craig and Gill 2020).

5.9 MQ-10 Does revegetating the drawdown zone affect the availability and use of habitat for waterbirds in Revelstoke Reach?

Revegetation efforts in Revelstoke Reach have had mixed results, and at some sites the success has not been discernable due to an inability to distinguish natural from hand-planted recruitment (Miller et al. 2016). Revegetation of the drawdown zone undoubtedly increases habitat available to waterbirds, but whether this is beneficial is arguable (Reitan and Thingstad 1999, van Oort et al. 2015, 2018). Benefits of revegetation of the drawdown zone is dependent on the elevations being planted, and how benefit is perceived. If revegetation efforts occur at the lowest elevations, which are generally flooded prior to the beginning of breeding, these efforts can provide only stopover habitat during migration (**Error! Reference source not found.**). However, vegetation in the drawdown zone below ~ 439 m can create an ecological trap for nesting waterfowl and shorebirds if the habitat created is suitable for nesting (Craig and Gill 2020).

Using the CLBMON-36 (Craig and Gill 2020) data, the average date of first egg for waterfowl vulnerable to nest flooding was June 12, and the lowest elevation nest monitored was at 434.6 m ASL. In 17 of the past 34 years, the reservoir has flooded this elevation by the mean date of first egg for waterfowl, meaning efforts to revegetate the drawdown zone may result in nest mortalities.

Revegetation does not generally benefit shorebirds, as they select unvegetated, mucky substrates during migration and, as with waterfowl, these species nest low in the drawdown zone, exposing them to nest flooding if suitable habitat is available. Increased risk of nest flooding as a result of revegetation would be greatest for Spotted Sandpiper as they select sparsely vegetated sites, and have a later nesting phenology than Killdeer, which select bare ground and produce their first clutch generally well before inundation occurs (Oring et al. 1997, Jackson and Jackson 2000, Craig and Gill 2020).

5.9.1 Effects, Challenges, and Opportunities

This MQ has relatively low relevance to waterbirds other than as noted above. Revegetation had such low success rates that this MQ could not be assessed empirically. No specific surveys were conducted to assess this MQ.

5.10 MQ-11 Do physical works projects implemented during the course of this monitoring program increase waterbird abundance, or species richness, or indices of waterbird productivity?

Two wildlife physical works (WPW) projects outlined in CLBWORKS-29A have been implemented since the inception of this study – WPW 6a, and WPW 15 (Golder Associates 2009).

Completed in 2013, the focus of WPW 6a was to stabilize a channel and stop the erosion which threatened to drain Airport Marsh (Brunlees 2014). This project entailed the placement of rip-rap in the eroded channel making its way towards Airport Marsh from the Columbia mainstem, and had no direct influence on the marsh it was intended to protect. Because this project did not directly affect water levels in Airport Marsh, no changes to waterbird use were detectable.

WPW 15 in Cartier Bay was originally planned to raise water levels by 1 m and stabilize them by replacing a collapsed box culvert at the outflow of the wetland and repairing the historic Arrowhead railway railbed (Golder Associates 2009). In 2015, a collaborative study of the potential impacts to the wetland from this WPW was conducted, with results suggesting there was potential for negative impacts to birds, fish, and other wildlife (Hawkes et al. 2015). Recommendations from this report included stabilizing, but not increasing, the water depth of Cartier Bay. As a result of this study, this physical works was reduced in scope and the ad hoc dike holding back water in Cartier Bay was stabilized in 2015. As with WPW 6a, no change to water level in the wetland occurred, and thus no change to abundance and diversity of waterbirds was detectable.

While it is unlikely these projects have increased habitat values for waterbirds outlined in the MQ, these projects were critical in that they have reduced the chances that these two key wetlands would be compromised by failure of natural and artificial dikes.

5.10.1 Effects, Challenges, and Opportunities

Addressing this MQ did not require empirical study. Because the intention of the physical works projects was to have zero effect, and this was achieved, it would be very challenging to attribute any detected changes to these projects. Changes were therefore not tested empirically.

The true effectiveness of the two completed WPW projects will depend on their success at abating erosional processes. Monitoring erosion was not within scope of this study, but is monitored under a companion study CLBMON-11B4.

Originally, CLBWORKS-29a proposed eight physical works projects which were considered feasible (Golder Associates 2009). However, these projects were identified at the beginning of the WLR studies in 2008. The knowledge resulting from the WLR studies has proven valuable in understanding how physical works projects should be implemented, and what risks are involved with modifying the existing habitat in the drawdown zone. Physical works projects have great potential for improving, and protecting habitat in the drawdown zone, but like revegetation, must be considered carefully prior to implementation. We strongly recommend that biologists with expertise in wildlife and fish studies in ALR be consulted before designing future WPW projects so that unintended negative effects can be avoided.

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7 APPENDICES

7.1 Seasonal and annual variation in the abundance of waterbirds during the migration

In this analysis we characterize the seasonal and annual variation in waterfowl use of the study area during spring and fall migrations. For this analysis, 'seasonal and annual variation' considers observed maximum counts (population size recorded during a survey) for all species of waterfowl observed on the ground or in water within the wetland study areas monitored during Land-based Surveys (Cooper Beauchesne and Associates 2017a). These differences are compared between spring and fall migrations, and among years.

7.1.1 Methods

The analysis was performed on the Land-based Waterbird dataset (Section 4.2.1). From the data, two groups of birds were recognized and analyzed separately: (1) waterfowl, and (2) Canada Goose (see Section 1.2). Canada Goose abundance was analyzed separately from other waterfowl. By sheer numbers, Canada Goose overwhelms any signal from other waterfowl species and including them risks skewing results. Data were then aggregated to each wetland on each survey occasion.

Land-based observations were recorded as count data, which was found to have a high proportion of low counts (occasions with low, or near-zero detections) or overdispersed (variance greater than the mean). Initially, a quasi-Poisson model was fit to the data, but the data were found to be overdispersed ($\Phi = 87$). Overdispersion was assessed by calculating the sum of squared residuals and dividing this by the residual degrees of freedom. This overdispersion was resolved by using a negative binomial GAM ($\Phi = 0.96$). All models were fit using the mgcv package in R (Wood 2011).

Seasonal peaks of migration were evaluated using year-round observations of waterfowl excluding Canada Goose. However, winter surveys were only conducted between 2009 - 2013. Among years, an ANOVA was used to determine differences in counts using the same subset of data as was used for seasonal variation (waterfowl excluding Canada Goose).

Measures of changes in diversity was done by subsetting the land-based waterbird dataset to remove unknown species, and focusing on periods of migration. Data were summarized by year, and the total number of surveys, number of species, and number of waterbirds were calculated. This dataset was examined graphically, with a linear regression line added to show trends in diversity.

7.1.2 Results

There were two seasonal peaks in migration intensity for ducks (Figure 22: Seasonal peaks of migration for waterfowl excluding Canada Goose.Figure 22). The negative binomial GAM was the best fit for the data (the model explained 57% of the variability, n = 364). There was a strong seasonal effect, predicting abundance of waterfowl, detected by the model ($P < 0.001$).

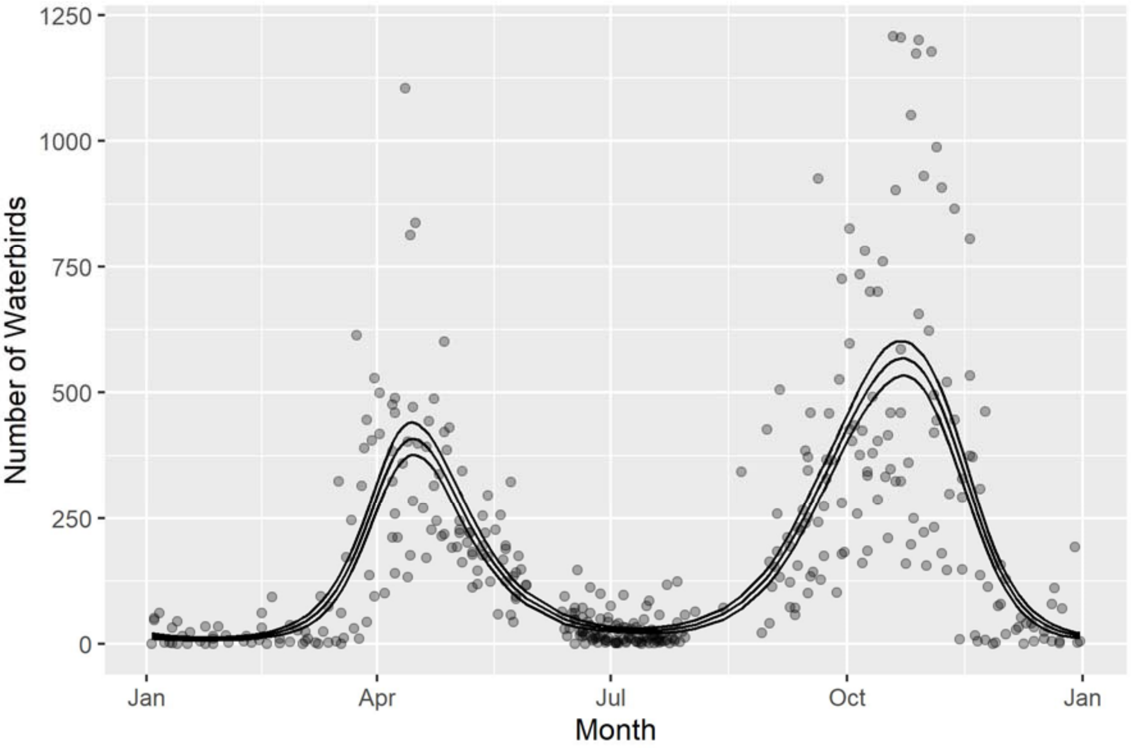

Figure 22: Seasonal peaks of migration for waterfowl excluding Canada Goose.

Among all years, an ANOVA indicated that peak counts differed among seasons (P = 0.0012); spring peak counts were estimated to be 408, and fall peak counts were estimated to be 567. Across years, extreme small migrations were observed in 2017 (392) in the spring, and 2015 (420) in the fall; and large migrations in 2011 (1112) in the spring and 2016 (1208) in fall.

Controlling for effort, variation among years in spring and fall migrations was pronounced with the smallest migration in the spring seen in 2009 with 410.9 birds/survey (n = 11 surveys) and the largest spring migration in 2013 with 632 birds/survey (n = 11 surveys). Fall migrations were similarly variable with the smallest fall migration recording 467.1 birds/survey in 2015 (n = 11 surveys), and the largest fall migration was in 2016 with 938.4 birds/survey (n = 11 surveys). Appendix 7.13 summarizes total counts of waterbirds (all birds detected), effort and diversity for spring and fall surveys for each year.

Canada Goose was the most abundant species detected, with 63,176 (maximum number of birds/survey in 2013 of 230) counted over the course of the study. American Wigeon were the second most commonly detected species (maximum birds/survey in 2009 of 158, total count of 34,476), followed by Mallard (maximum birds/survey of 100 in 2014, total count of 22,188). American Coot were an irruptive species which did not occur in the same overall abundance as the other species, but had the highest recorded birds/survey of 294 in 2016, but only a total of 12,538 total detections. Seldomly detected species included Greater White-fronted Goose, Double-crested Cormorant, Pacific Loon, White-winged Scoter, American White Pelican, Eurasian Green-winged Teal, and Red-breasted Merganser, all with fewer than 10 detections.

7.2 Spatial distribution of waterfowl throughout the study area

In this analysis, we examined how waterfowl are distributed throughout the entire Revelstoke Reach study area. To avoid spatial bias that is inherent to access, the aerial survey method was necessary. The use of aerial methods means that smaller-bodied waterbirds, namely shorebirds, are largely not represented in this analysis. Shorebirds were analyzed separately; distribution and abundance of shorebirds is included in Section 7.9.

7.2.1 Methods

Aerial waterfowl surveys occurred weekly during migration beginning in 2009. These surveys were scheduled to capture data over the course of migration, and to build a database of distributions over a range of reservoir elevations (weather conditions permitting). For a full description of aerial waterfowl survey methods see (Cooper Beauchesne and Associates 2017a).

Data from the helicopter-based aerial waterbird surveys were used to analyze spatial variability and were subsetted to include only those surveys which sampled the entire study area, meaning some earlier surveys were dropped from the analysis (total n = 45 complete surveys for this analysis). Waterfowl species were grouped into guilds based on similar species and feeding strategies, so distribution of specific species (aside from Canada Goose) were not analyzed. Guilds of birds examined in Table 7-1.

Table 7-1: Waterfowl species considered for the analysis of spatial distribution of birds throughout Revelstoke Reach.

Guild	Species Name	Scientific Name
Dabbling Duck	Wood Duck	*Aix sponsa*
	Gadwall	*Anas strepera*
	Eurasian Wigeon	*Anas penelope*
	American Wigeon	*Anas americana*
	Mallard	*Anas platyrhynchos*
	Blue-winged Teal	*Anas discors*
	Cinnamon Teal	*Anas cyanoptera*
	Northern Shoveler	*Anas clypeata*
	Northern Pintail	*Anas acuta*
	Green-winged Teal	*Anas crecca*
	Unknown Teal	-
Diving Duck	Canvasback	*Aythya valisineria*
	Redhead	*Aythya americana*
	Ring-necked Duck	*Aythya collaris*
	Greater Scaup	*Aythya marila*
	Lesser Scaup	*Aythya affinis*
	Surf Scoter	*Melanitta perspicillata*
	White-winged Scoter	*Melanitta fusca*
	Bufflehead	*Bucephala albeola*
	Common Goldeneye	*Bucephala clangula*

Guild	Species Name	Scientific Name
	Barrow's Goldeneye	*Bucephala islandica*
	Hooded Merganser	*Lophodytes cucullatus*
	Common Merganser	*Mergus merganser*
	Red-breasted Merganser	*Mergus serrator*
	Ruddy Duck	*Oxyura jamaicensis*
	Goldeneye sp.	*Bucephala sp.*
	Scaup sp.	-
Grebe	Common Loon	*Gavia immer*
	Pied-billed Grebe	*Podilymbus podiceps*
	Horned Grebe	*Podiceps auritus*
	Red-necked Grebe	*Podiceps grisegena*
	Eared Grebe	*Podiceps nigricollis*
	Western Grebe	*Aechmophorus occidentalis*
	Unknown Grebe	-
Gull	Bonaparte's Gull	*Chroicocephalus philadelphia*
	Ring-billed Gull	*Larus delawarensis*
	California Gull	*Larus californicus*
	Herring Gull	*Larus argentatus*
	Gull sp	-
	Unknown Larus Gull	*Larus sp.*

Observations from each complete survey occasion were assigned to each of the primary wetlands or to a general geographic location denoted as Revelstoke Reach (for observations which fell beyond the boundaries of identified wetlands)[5]. The proportion of total count for each wetland for each season was then calculated and used as the relative measure of abundance of waterfowl and Canada Goose separately.

These surveys were used to determine the distribution of waterfowl throughout the study area but were not intended to identify important habitats within wetlands.

7.2.2 Results

Patterns noted in the land-based survey data were reflected in the aerial survey dataset as well. Wetlands were primarily selected during migration, but differently between spring, when these wetlands were less likely to be inundated, and the fall when they were more frequently inundated by the reservoir. In the spring Cartier Bay had the highest use, followed by Airport Marsh, Montana Bay and Airport West (Figure 23). Cartier Bay emerged as the most important wetland from both land-based and aerial datasets for waterfowl (excluding Canada Goose) when it was not inundated. The wetlands in the study area account for 491 hectares, while non-wetland habitat of Revelstoke Reach accounts for 5021 hectares, further illustrating the disproportionate use and importance of the wetlands for migratory waterfowl.

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[5] Wetlands: Airport Marsh (AM), Airport West (AW), Cartier Bay (CB), Downie Marsh (DM), Locks Creek Outflow (LCO), Montana Bay (MB), Machete Pond (MP), Revelstoke Reach (RR).

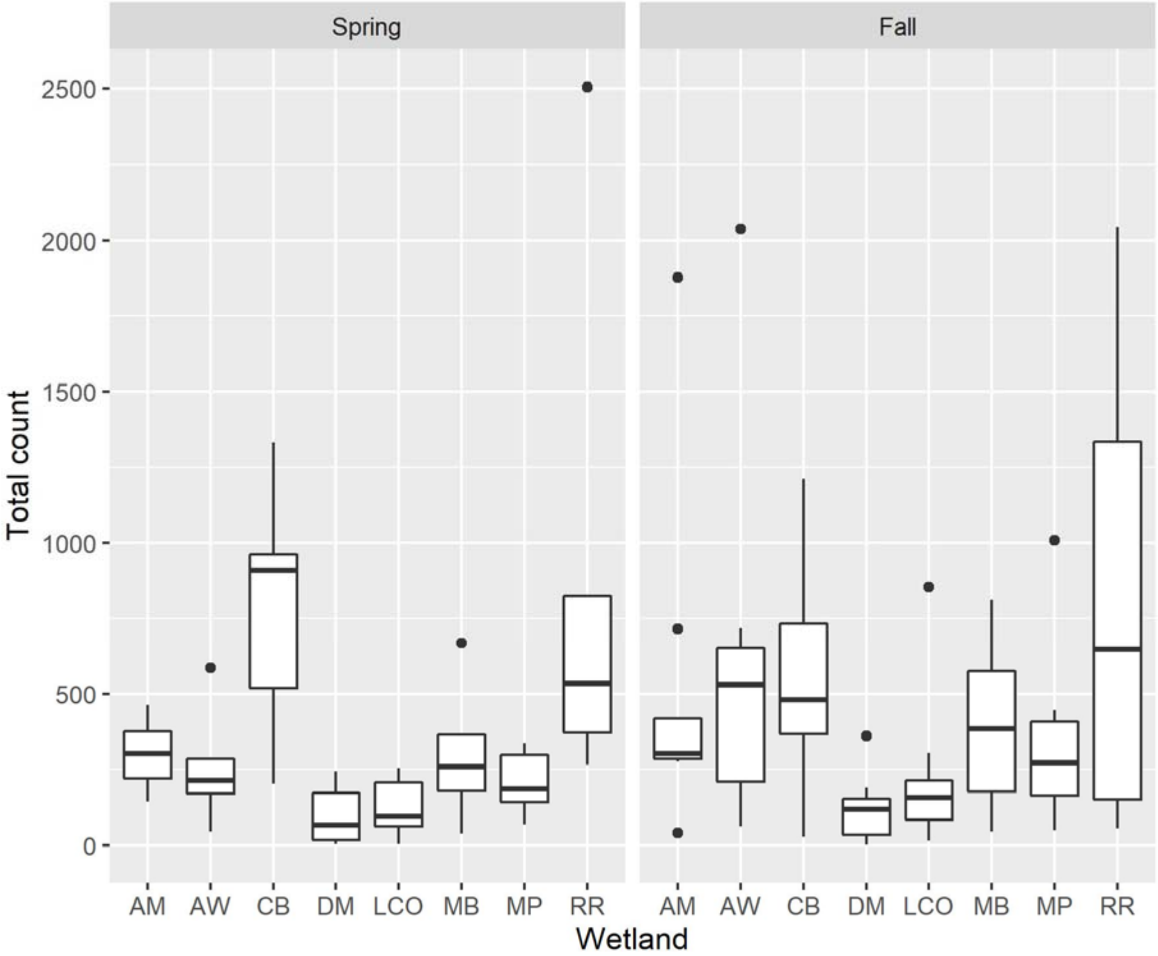

Figure 23: Waterfowl distribution among each of the primary wetlands during spring aerial waterfowl surveys.

The predominant observations from polygons delineated as Revelstoke Reach in the fall came from Canada Goose, which were mostly observed south of the Akolkolex River, staging in open water areas while their flight feathers molted. Including Canada Goose in the counts for each polygon shows how they dominate counts, particularly after the brood rearing period and before they can fly after molting (Figure 24).

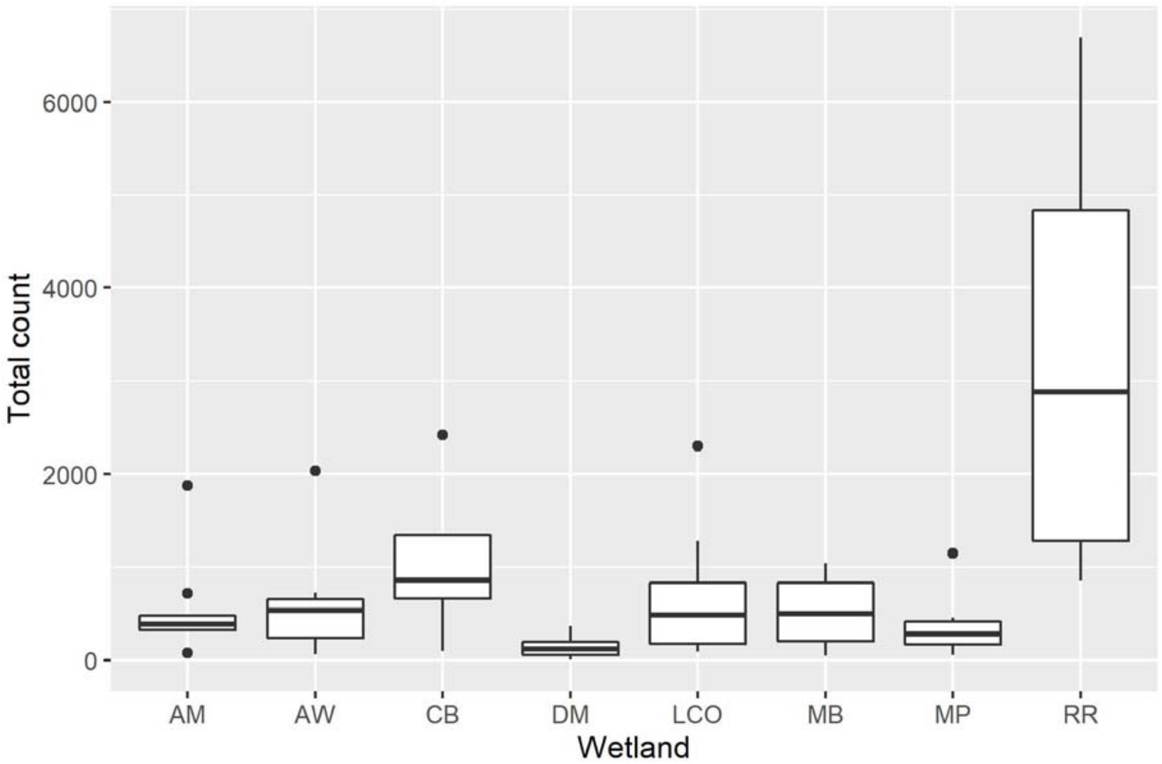

Figure 24: Total count of all waterfowl detections for each wetland or major river feature in Revelstoke Reach during fall migration. Large numbers of Canada Goose staged south of the Akolkolex River while their flight feathers molted.

7.3 Seasonal and annual variation in the abundance of shorebirds during the migration

In this analysis we characterize the variation in seasonal and annual variation in shorebird use of the study area during the fall migration. For this analysis, 'seasonal and annual variation' considers observed maximum counts (population size recorded during a survey) for all species of shorebird observed on the ground during Shorebird Surveys (Section 4.2.3). These surveys only occurred in the fall. The primary goal was to determine timing, species composition and distribution of birds throughout the study area during fall migration.

7.3.1 Methods

Shorebird data from 2008 were excluded due to incompleteness. When shorebird counts were summed within years, the last (unusually late) survey in 2009 was omitted in order to equalize the survey effort among years; when data were analyzed using survey occasions as the sample unit, all occasions were used.

Data were further subset to eliminate unknown shorebird species, but also many genera were grouped which had similar timing of migration, and behaviours. We grouped all *Calidris* sandpipers together as '*Calidris* sp.', Long and Short-billed Dowitcher as 'Dowitcher sp.', and both Greater and Lesser Yellowlegs as 'Yellowlegs sp.'. Other species were more easily identified in the field and analyzed alongside these groups.

To determine seasonal abundance of shorebirds similar methods as were used to assess seasonality of waterfowl migration (Appendix 7.1). However, each species, or group of species (Calidris sp., Dowitcher, Yellowlegs, Wilson's Snipe, Spotted Sandpiper, and Killdeer) were modeled independently. Species which occurred very rarely, which did not fall within those groups or individual species were excluded.

Data analysis centered around responses of individual species, or groups of species to seasonality. As with the waterfowl migration data, the shorebird data were biased towards low or near-zero counts on many occasions and were slightly overdispersed, consequently ($\theta > 20$), a negative binomial GAM was fit to the data. For shorebirds, the irruptive nature of some species among years meant that the addition of 'year' as a model term improved the model result. Data were plotted using a Loess smoothing function to illustrate seasonality.

7.3.2 Results

As with the waterfowl data within years, shorebird count data had many occasions of low or zero counts throughout the season (Figure 25). To accommodate for the variability in counts, seasonal abundance for each of the species was assessed with a negative binomial GAM. The best fit model for Spotted Sandpipers and Dowitcher species showed a moderately - strong seasonal effect for both (SPSA: $R^2 = 0.34$, deviance explained = 46.4%, Dowitcher sp.: $R^2 = 0.25$, deviance explained 33.8%) (**Error! Reference source not found.**). These results indicate variability within the season, but the *P* value for the term 'year' was not significant for either species ($P_{spsa} = 0.124$, and $P_{Dow} = 0.737$). For *Calidris* sp. (a group of shorebird species that are small in size and difficult to identify in the fall), the abundance of species in this genus varied strongly both within and among years ($R^2 = 0.19$, deviance explained = 43.1%).

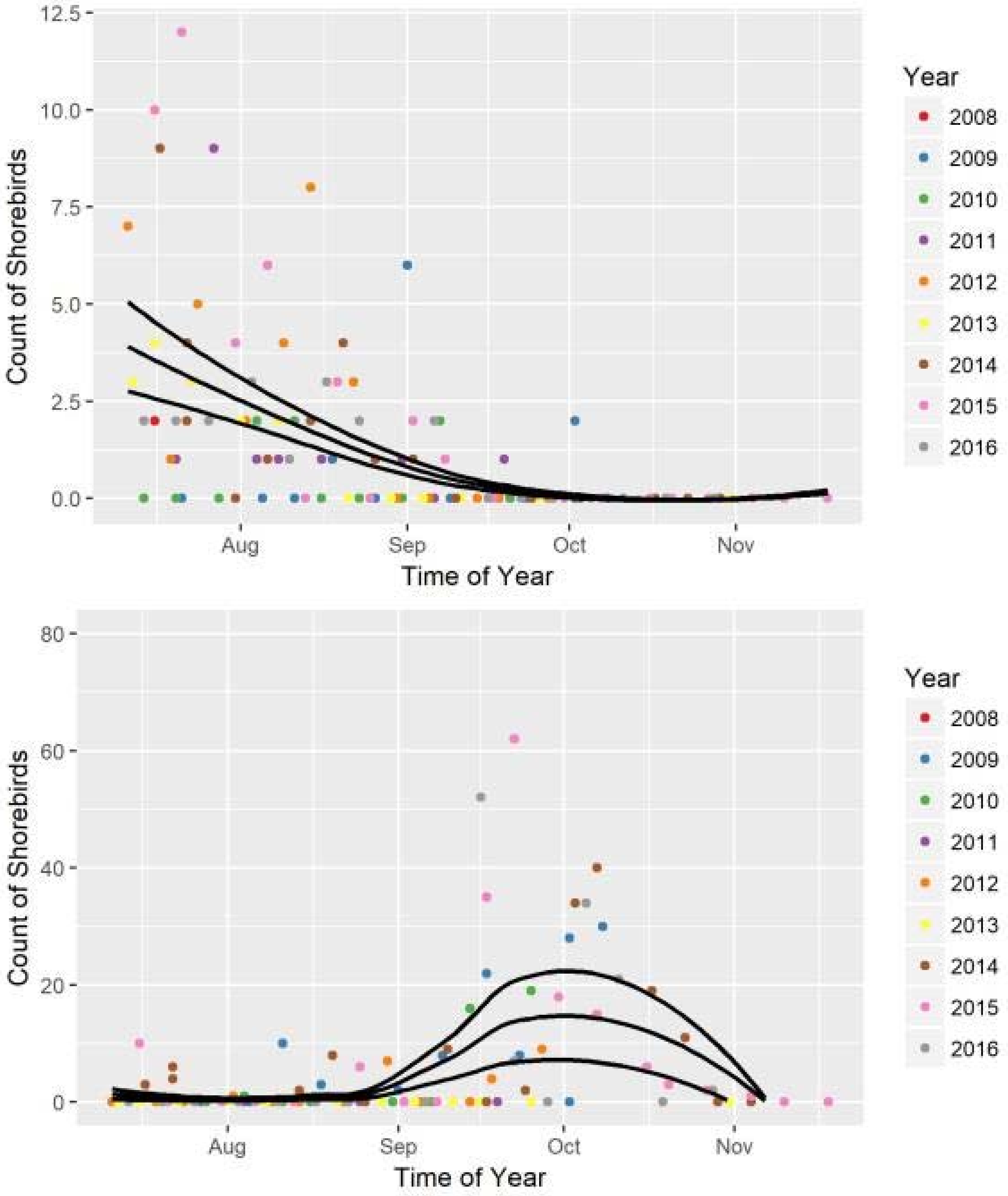

Figure 25: Seasonal variability in counts of Spotted Sandpiper (top) and Dowitcher species (bottom) during fall migration. Central line is mean, and the associated upper and lower lines represent standard error.

Dowitcher sp. and Spotted Sandpiper were the most abundant shorebirds in the study area during migration throughout the study period. Spotted Sandpipers accounted for 29% and Dowitcher sp. accounted for 25% of detections among all years during fall migration (Appendix 7.15). *Calidris* sandpipers collectively accounted for 13% of shorebirds detected. *Calidris* sandpipers were very sporadically detected, and their presence was more often informed by anecdotal observations, than by detections on surveys due to their selection of habitat on very small scales.

7.4 Habitat Selection Within Wetlands

Here we consider what habitat attributes were being selected by dabbling ducks during spring migration. Spring migration was selected because during this period the reservoir was not influencing waterfowl use of wetlands through inundation (Section 5.6). Habitat elevation was discounted as an important predictor because the extreme difference in elevations seen across the two most important wetlands (Airport Marsh and Cartier Bay), thus demonstrating that wetland position in the drawdown zone is a poor predictor of habitat quality. The distance to water's edge was also not considered because this is typically correlated with water depth, and water depth is known to be an important facet of habitat suitability of waterbirds (Colwell and Taft 2000). For the reason that water depth is known to be important for dabbling duck morphology and feeding (Pöysä 1983, Colwell and Taft 2000), water depth was not further examined here. We focussed on vegetation selected by ducks which was characterized by the distribution of aquatic macrophytes. The analysis was constrained to the two most important wetlands: Airport Marsh and Cartier Bay. These wetlands have a wealth of data, and also span two extreme types of functional habitat: a high elevation marsh complete with emergent vegetation, and a low elevation pond without emergent vegetation.

7.4.1 Methods

Within wetland habitat-use variability was characterized using the land-based waterbird survey data (Section 4.2.1), combined with detailed habitat sampling from CLBMON-11B-4 (Miller and Hawkes 2014), to examine how aquatic macrophytes are associated with fine scale locations and behaviour of waterfowl. See Section 7.1.1 for a detailed description of land-based waterbird survey data capture methods.

Only data from dates when the reservoir does not inundate wetlands were analyzed, ensuring the aquatic features identified by CLBMON-11B-4 were within a natural range of the water surface. The land-based waterbird dataset was further subsetted to only compare years of land-based survey data which coincided with sampling for CLBMON-11B-4 (2011, 2012, and 2013).

Observations of dabbling ducks (species, group size, etc) were mapped as polygons as accurately as feasible during land-based surveys. Area for each mapped polygon of bird locations was calculated and this was used to define the density of birds (birds per hectare). The observations were then assigned to a grid for each occasion, which was then rasterized to produce a raster with cell values representing the density of birds at a given 10m x 10m grid cell (birds/hectare). The rasters for each survey occasion within a year were then stacked, and summed. This resulted in areas of repeated use having higher bird density values. For the analysis, the densities for each of the years (2011, 2012, 2013) were summed to produce a relative measure of use among sampled sites (multi-year density).

Aquatic macrophyte data from CLBMON-11B4 were recorded at point locations at Airport Marsh (n_{2011} = 29, n_{2012} = 37, n_{2013} = 30 CLBMON-11B4 plots) and Cartier Bay (n_{2011} = 23, n_{2012} = 24, n_{2013} = 15 CLBMON-11B4 plots). Dabbling duck density values from the raster cell within which the CLBMON-11B4 plots were assigned to the plot data to create a dataset of 158 point locations where waterfowl density could be contrasted with attributes of each CLBMON-11B-4 sample location[6]. Differences in bird density as a function of the attributes of each vegetation plot was then examined.

Points sampled under CLBMON-11B-4 were treated as independent samples. Despite repeated plot names, plots among years were widely variable in their placements and visual inspection in a GIS confirmed their spatial independence.

The availability of each aquatic macrophyte species was quantified by summing the number of plots that each macrophyte occurred at (Appendix 7.20).

For each macrophyte species, the duck usage at each set of plots where the particular macrophyte was present was contrasted by calculating the average multi-year duck density at these plots (Appendix 7.20). Duck density as a function of the relative abundance for each macrophyte was assessed to examine whether there were patterns of duck use for plots with higher abundances of specific macrophytes. Relative abundance was measured as a qualitative scale from 1 (less than 10% of plot covered by the species) to 5 (greater than 75% of plot covered by the species). The multi-year density was examined graphically to show changes in density as a function of the relative abundance of each macrophyte.

The depth at which each macrophyte was found was also examined as depth is a known predictor of dabbling duck habitat use (Colwell and Taft 2000). Data for all plots were pooled by aquatic macrophyte species and the range of depths of only aquatic, or wetland plants were examined. Comparing depths at which these aquatic plants grew, as a function of duck density again employed the multi-year density value for dabbling ducks. These relationships were examined graphically.

To explore if diversity of macrophyte species at each plot had a bearing on multi-year density, the number of macrophyte species at each plot was summed and used as a predictor of duck density using a linear model.

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[6] Depth, substrate, water clarity, dissolved oxygen, thatch cover, species name, species cover and relative abundance were collected under CLBMON-11B-4.

7.4.2 Results

There were 30 spring survey occasions in the years of CLBMON-11B-4 sampling and dabbling duck multi-year density ranged from 0 – 3009 birds/hectare (Figure 26). Only observations from Airport Marsh and Cartier Bay were included in these density estimates, so overall duck density for the entire study area will vary from this range.

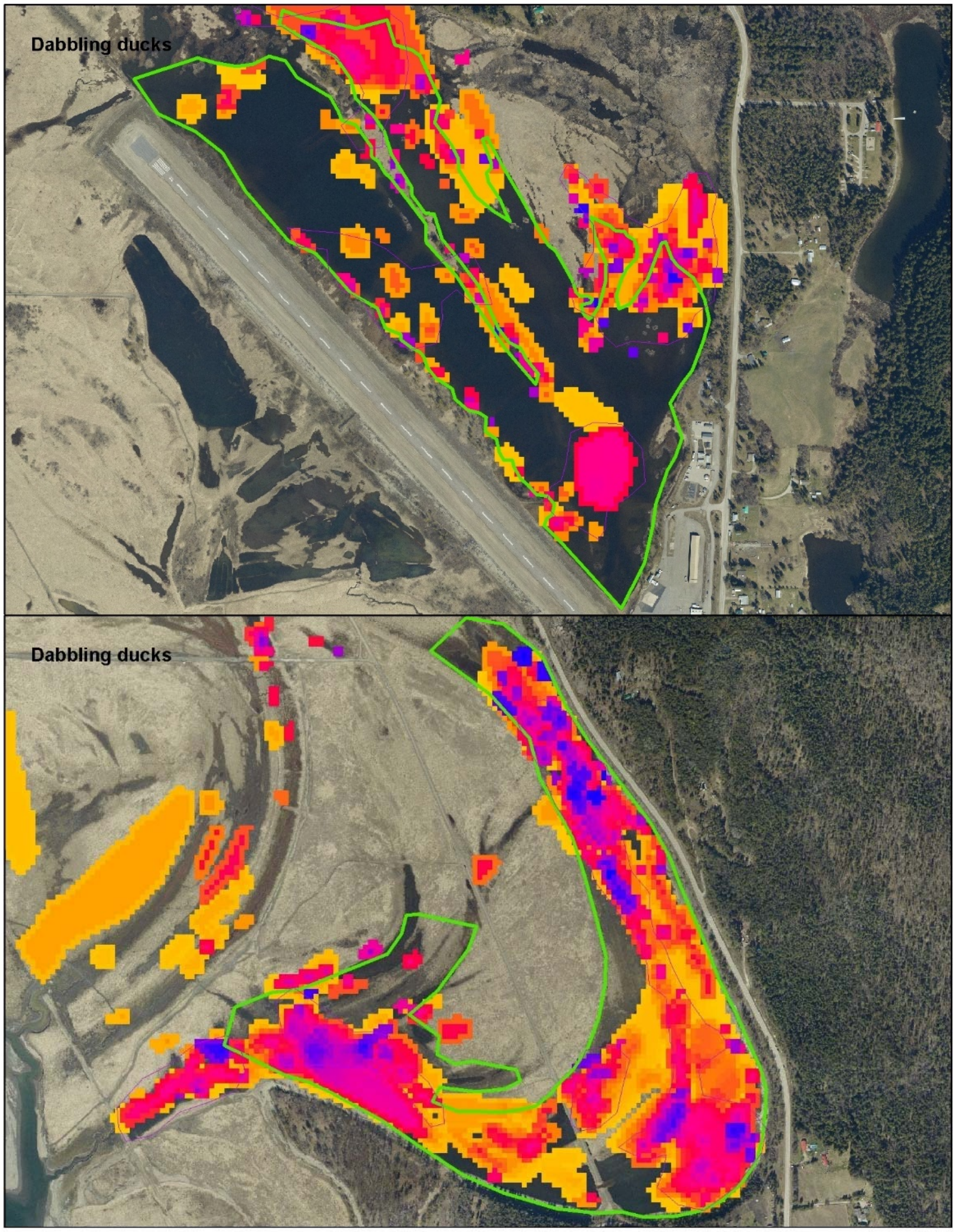

Figure 26: Distribution of dabbling ducks during spring migration in Airport Marsh (top panel) and Cartier Bay (bottom panel). Darker colours represent higher densities of ducks.

There were 10 macrophytes detected at 10 or more plots, with the most widespread macrophyte being *Myriophyllum spicatum*, which was detected at 58 plots. Most of these widespread macrophytes were observed at more Airport Marsh plots, except for *Ceratophyllum demersum*, which was observed at slightly more Cartier Bay plots (Appendix 7.20). The remaining 25 macrophytes were observed at fewer than 10 plots.

Among the more widespread macrophytes, *Persicaria amphibia* (found at 24 plots, mostly at Airport Marsh) had a high level of usage with a multi-year duck density of 84.9. *Potamogeton pusillus* was another widespread species at both wetlands, found at 53 plots with a high average multi-year density (56.8). *Myriophyllum spicatum*, and *Ceratophyllum demersum*, were two other species that were widespread with high densities of ducks (Appendix 7.20).

The macrophytes with the highest densities of ducks were species that were uncommon; for example *Sparangium natans* was observed at just one plot in Airport Marsh with a multi-year density of 91.6 birds/ha (Appendix 7.20). A very high density was also observed at 4 plots where moss was encountered – likely a shoreline area used for loafing by ducks. It is unlikely that rare species of plants explain the widespread and high usage of waterfowl at these wetlands, and such results should not be interpreted without more detailed information.

Diversity of macrophyte species at each plot was investigated to determine if it was variety, and not specific species of macrophyte which was appealing to ducks. A linear model was fit to the data, with density as the response, and the number of macrophyte species at each plot as the predictor. There was no clear affinity by ducks to those plots with a higher variety of macrophytes ($P = 0.27$).

Duck density as a function of the relative abundance of each macrophyte species was examined for all species of macrophyte, but only ten showed patterns of use (below, and Appendix 0). The macrophytes *Potamageton natans* and *Myriophyllum spicatum* are associated with high duck densities, but plots with lower relative abundance values are selected preferentially, suggesting ducks prefer this vegetation, but at low abundances (Figure 27).

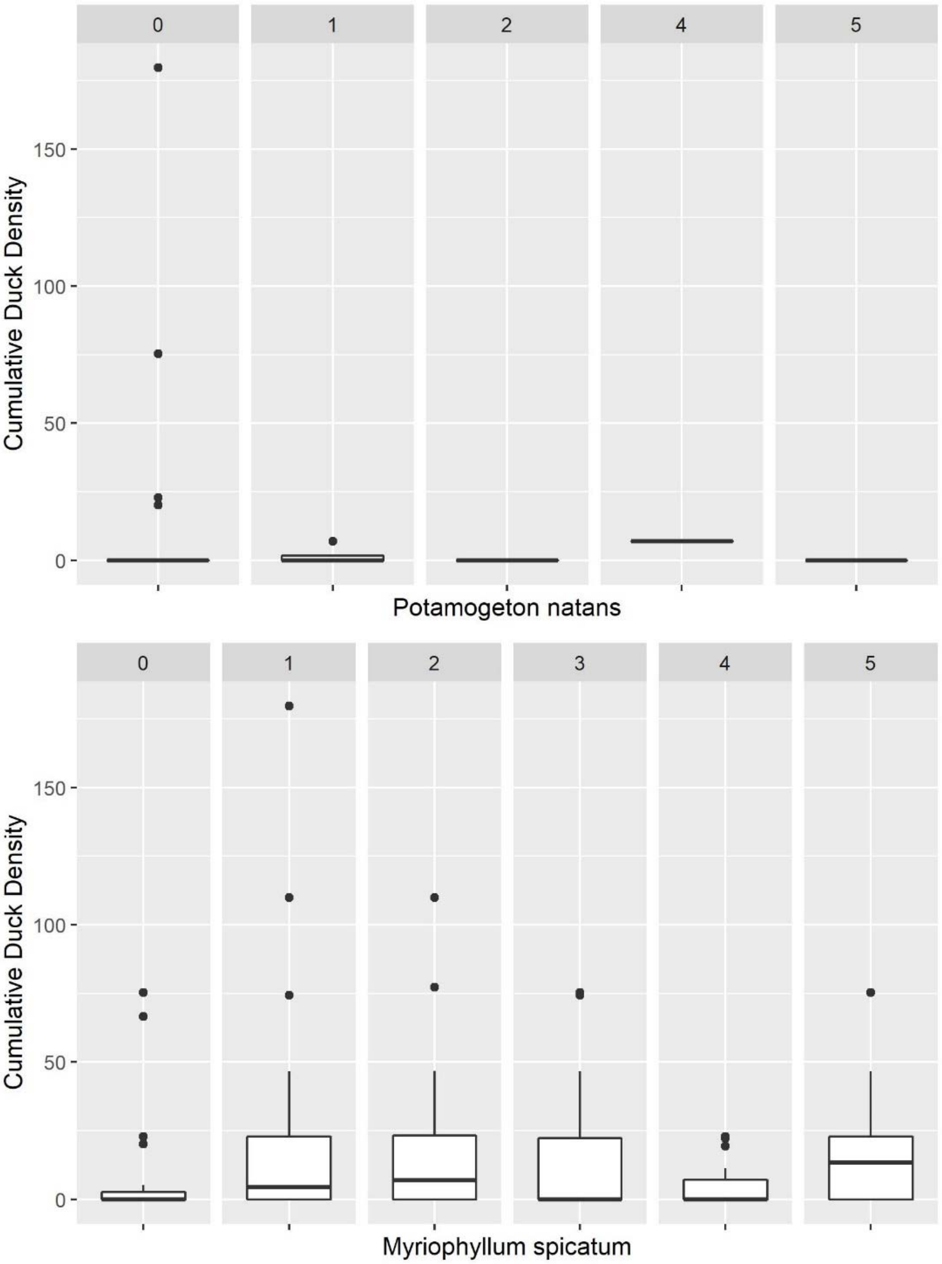

Figure 27: The change in duck density at different relative abundances of *Potamageton natans* and *Myriophyllum spicatum*

The macrophytes *Chara* sp. and *Potamageton pusillus* see increasing duck density with increased abundances of these macrophytes (Figure 28).

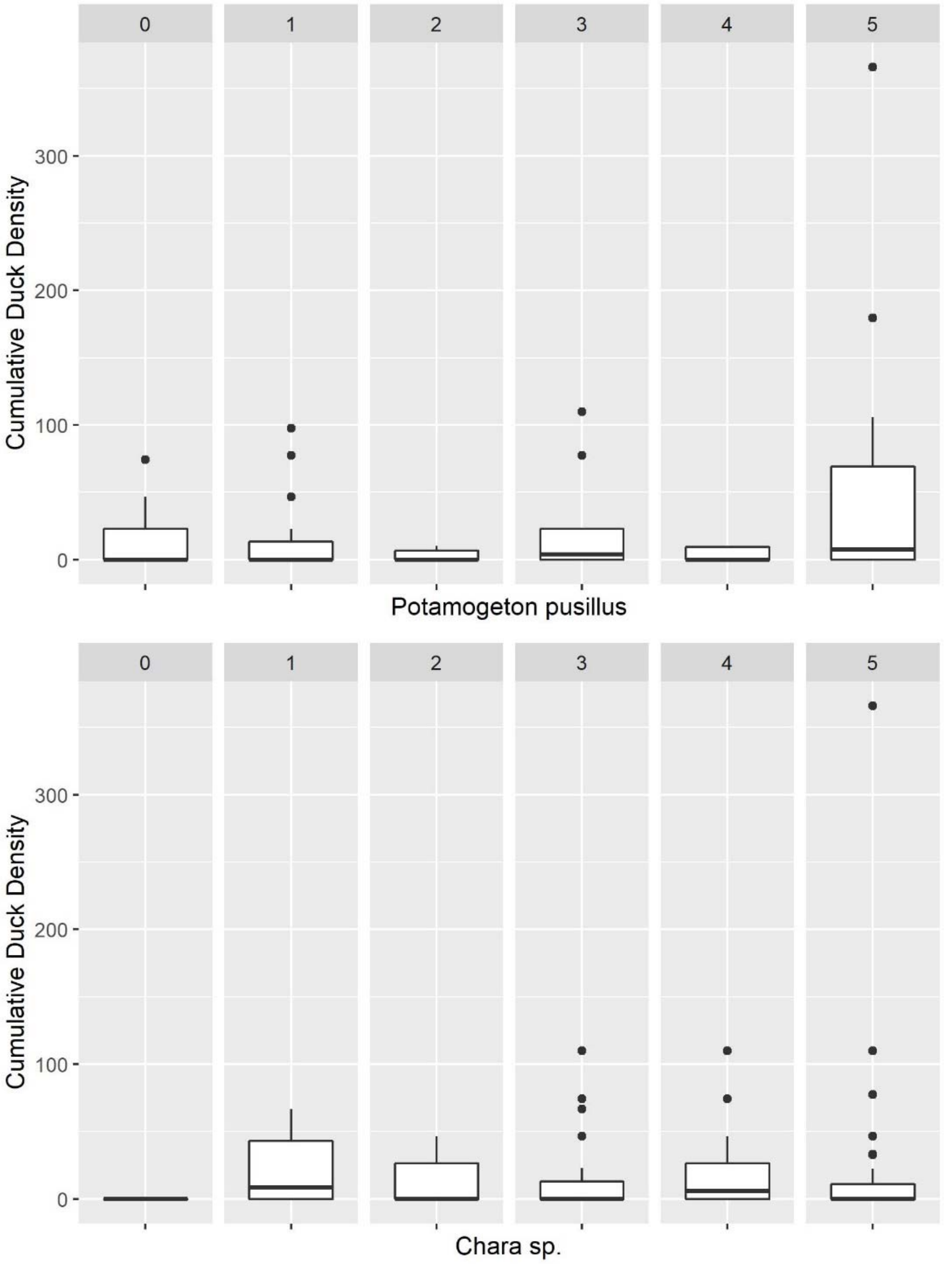

Figure 28: The change in duck density at different relative abundances of *Potamageton pusillus* and *Chara* sp.

Some vegetation saw other strong trends in use, moss sp. was highly selected for, with high duck densities associated with the highest relative abundance class of this vegetation, and with *Hippurus vulgaris* duck density was highest at the lowest abundance class and neared zero at the higher abundance classes (Figure 29). Moss is not an aquatic macrophyte, and this result showing a strong affinity for this vegetation type is likely a result of birds roosting along the shore of Cartier Bay, where moss is a common ground cover along the water edge. In addition, moss only occurs in areas with dominant abundance where aquatic macrophytes do not grow, so it either occurs as highly abundant, or near 0.

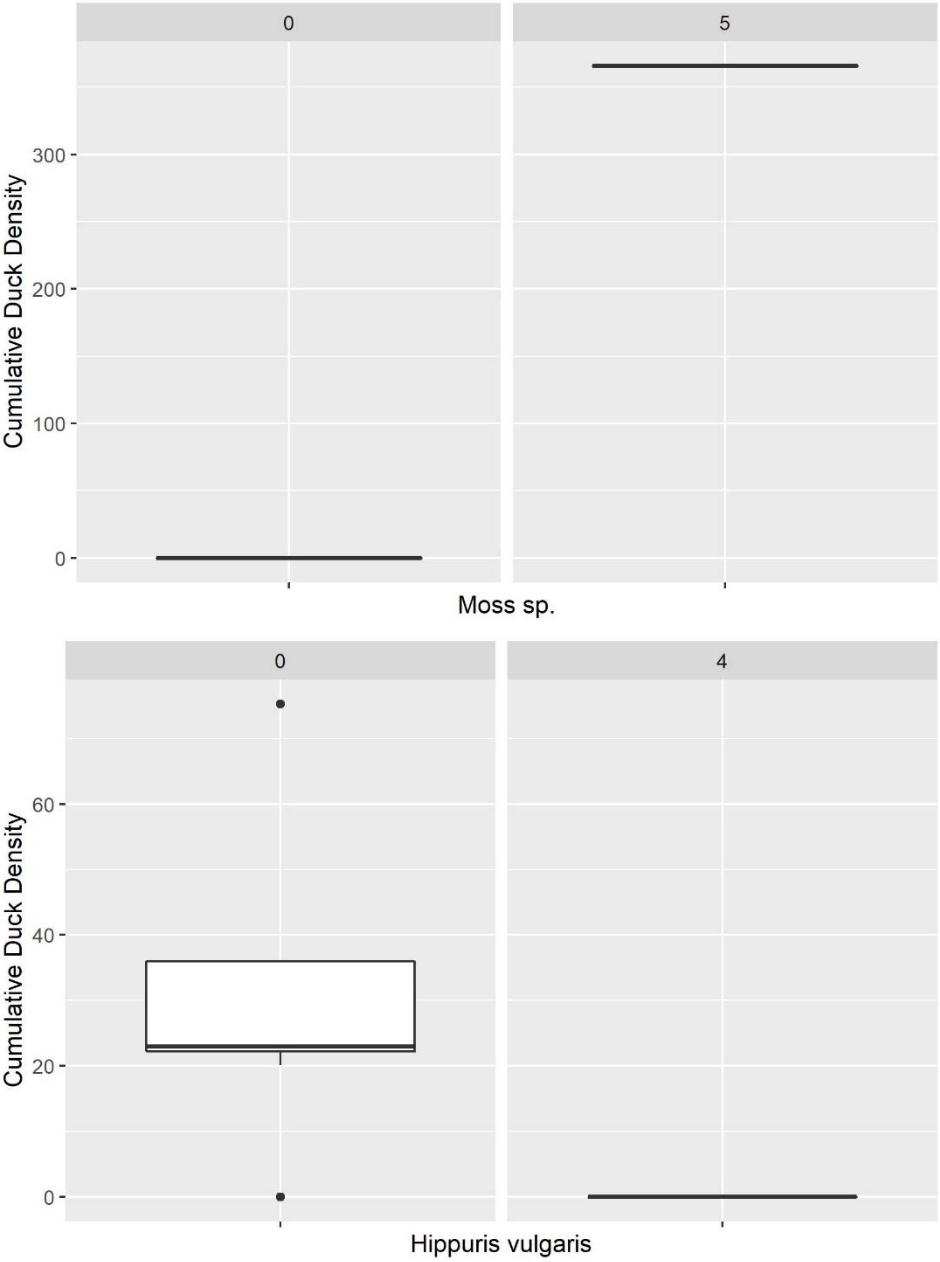

Figure 29: The change in duck density at different relative abundances of Moss sp., and *Hippurus vulgaris*

Each of these macrophyte species grows along a depth gradient, which is a well known predictor of duck use (Colwell and Taft 2000). Disentangling selection of habitat by ducks based on water depth, vs. macrophyte species is beyond the scope of this study, but below are presented the depth range at which each macrophyte species was found to grow. Comparing the depth range of growth for *Potamageton natans* and *Potamageton pusillus*, which have reverse trends of use with increasing abundance, suggests that the depth similar macrophytes grow at has implications for their use by ducks (Figure 30).

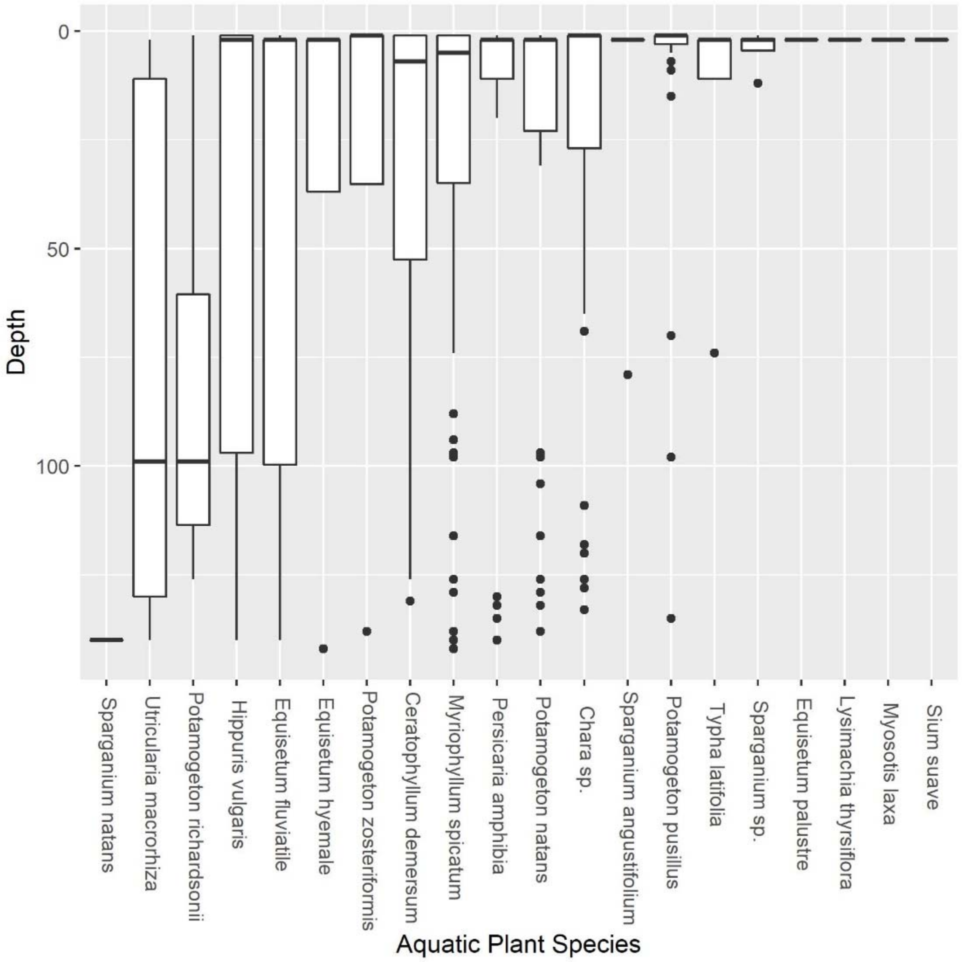

Figure 30: The range of depths at which aquatic species are found. The colour in this figure represents whether dabbling ducks are positively (light green) or negatively (orange) associated with each plant species for all sites.

Figure 31 plots dabbling duck density against aquatic macrophytes. Comparing Figure 30 and Figure 31 illustrate how duck density is highest at plots with aquatic macrophytes which grow a medium depths.

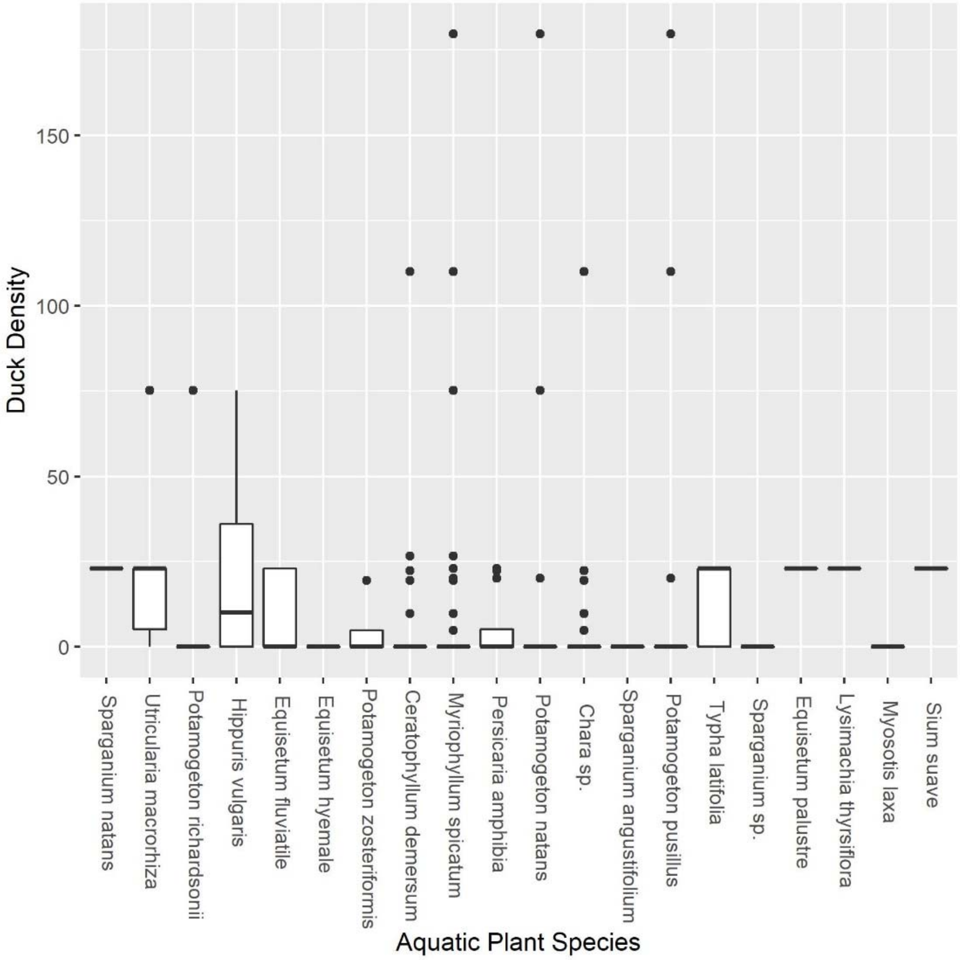

Figure 31: Dabbling duck density plotted against aquatic macrophytes found in Cartier Bay and Airport Marsh.

7.5 Temporal and Spatial Variation in Waterfowl Productivity

This analysis focused on waterfowl distribution observable during brood surveys (Section 4.2.1). Counts of waterfowl broods were used as an index of productivity among years, as well as among wetlands in Revelstoke Reach.

7.5.1 Methods

This analysis focussed on species with exposure to flooding: ground-nesting species in the drawdown zone (American Wigeon, Mallard, Northern Shoveler, Pied-billed Grebe, Ring-necked Duck, and Wilson's Phalarope). Canada Goose was analyzed separately due to their high abundance, and reduced exposure to nest-flooding.

A nine-year data set was analyzed; brood survey data were unreliable in the first year of the study due to methodological issues, so 2008 data were censored. Data were also subset to focus on the period when brood surveys were consistently conducted among years: June 19th to July 20th. The number of broods and young per week were tallied separately for all waterfowl. Data was divided into years and weeks within year to better estimate the exposure of broods to annual and seasonal reservoir operations.

To assess spatial variability, brood detections were assigned to each of the key wetlands or landscape features (in addition to the key wetlands, the areas of 9 mile and 12 mile were considered, but assigned to 'Revelstoke Reach' [Figure 1]).

To examine where broods may originate from, data were subset to include only observations of the youngest broods (age 1a according to (Gollop and Marshall 1954)). Brood numbers of this young age, and their distribution among wetlands provided a way of identifying areas which likely provide more productive nesting.

7.5.2 Results

Which species were observed with broods?

Few species of waterfowl nested in the study area, and only 9 waterfowl species were found with broods (American Wigeon, Canada Goose, Common Merganser, Mallard, Northern Shoveler (one brood), Pied-billed Grebe, Ring-necked Duck (one brood), Wilson's Phalarope (one brood) and Wood Duck).

Annual variation in brood abundance

Variation in brood counts was pronounced among years both for waterfowl (minimum total detections of 2 in 2013, maximum total of 42 in 2015) and Canada Goose (minimum total detections of 2 in 2015, maximum total of 81 in 2009) (Section 4.2.1).

Seasonal variation in brood abundance

Canada Goose brood counts declined as the summer progressed coinciding with further dispersal of surviving broods. Waterfowl initiated nests later than Canada Goose, and their broods were detected in increasing numbers during the same period as Canada Goose brood detections were decreasing (Figure 32).

Spatial variation in brood distribution

There was uneven distribution of waterfowl broods throughout the surveyed area. Excluding Canada Goose, the Airport Marsh emerged as a high-use brood rearing area, followed by Downie Marsh (Figure 33).

Age 1a broods were only detected at four wetlands (Airport Marsh, Cartier Bay, Downie Marsh and Locks Creek Outflow). Downie Marsh emerged as the wetland with the highest proportion of young broods detected, with half of all detections (Figure 34).

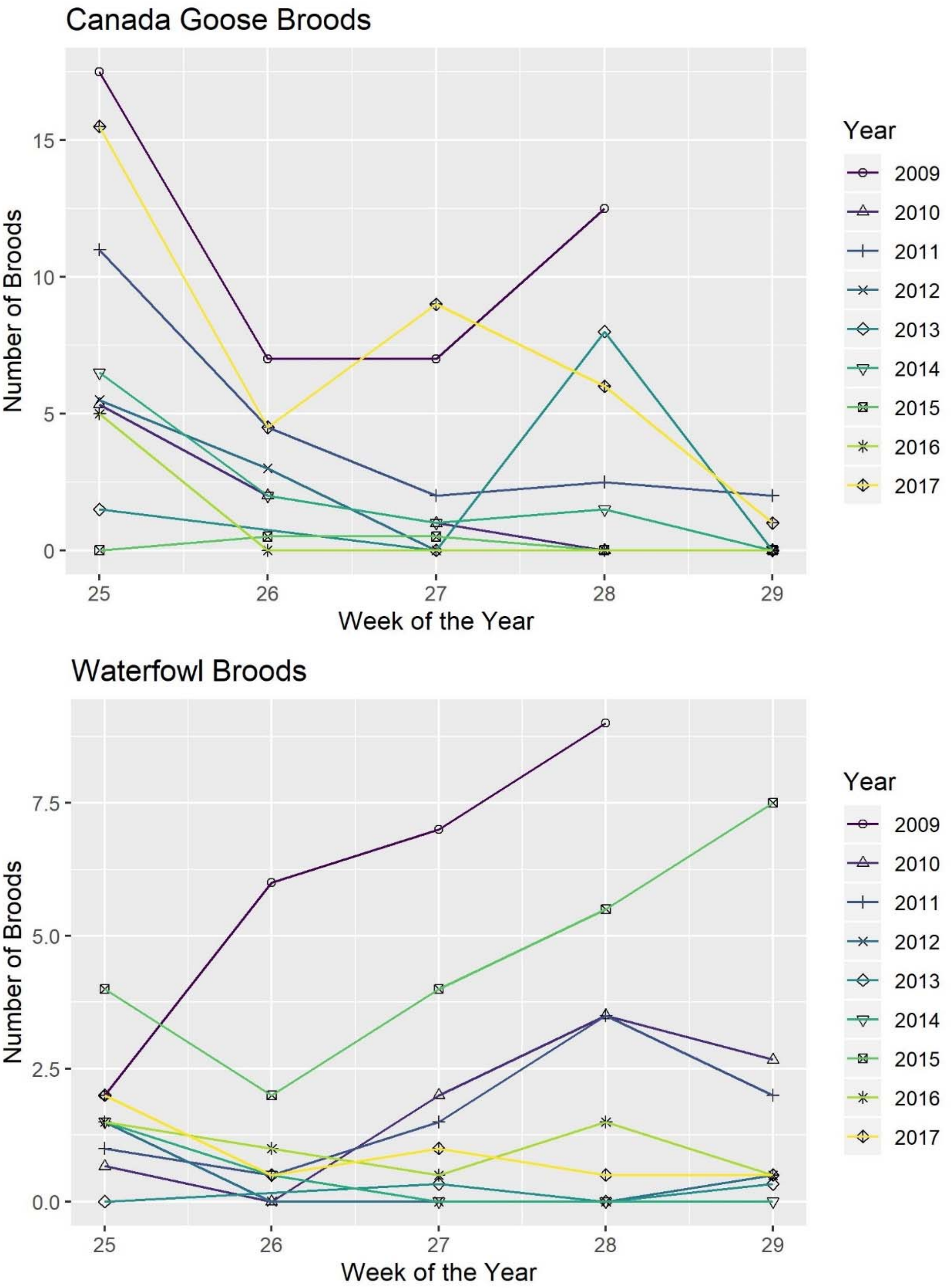

Figure 32: Trends in temporal detections of Canada Goose broods (top) and waterfowl broods (bottom).

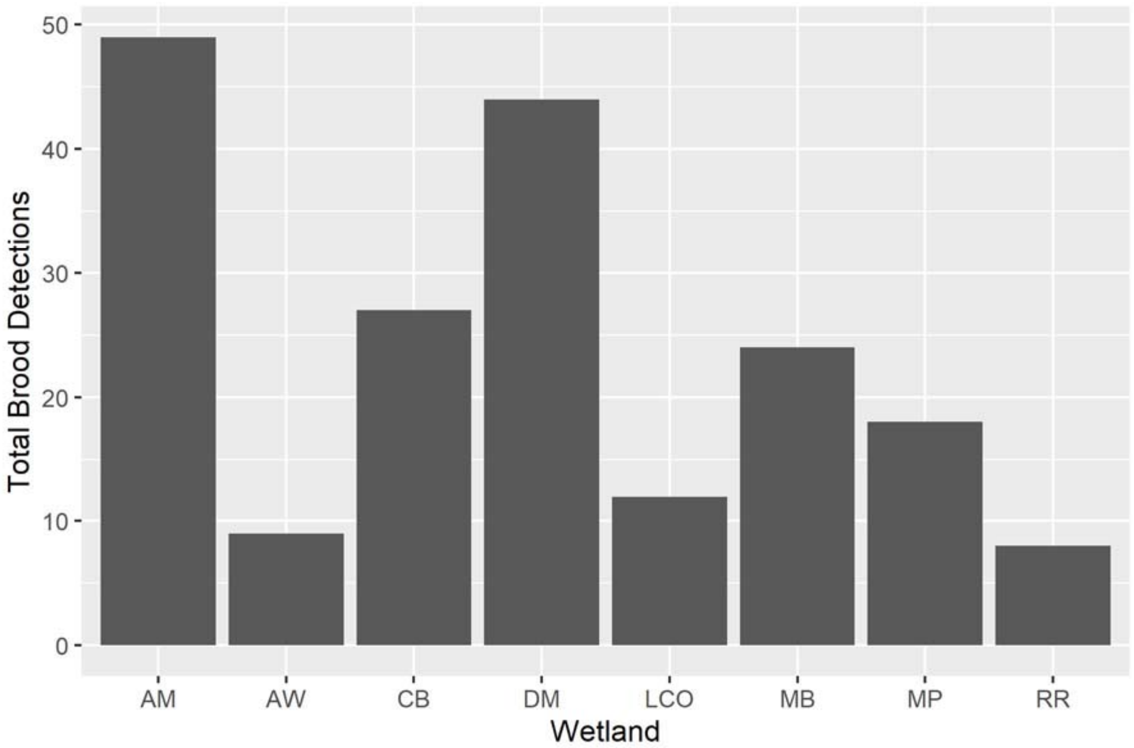

Figure 33: Wetland use by all ages of waterbird broods not including Canada Goose summed for all years. RR = Revelstoke Reach, AM = Airport Marsh, AW = Airport West, CB = Cartier Bay, DM = Downie Marsh, LCO = Locks Creek Outflow, MB = Montana Bay (includes associated ponds), and MP = Machete Ponds.

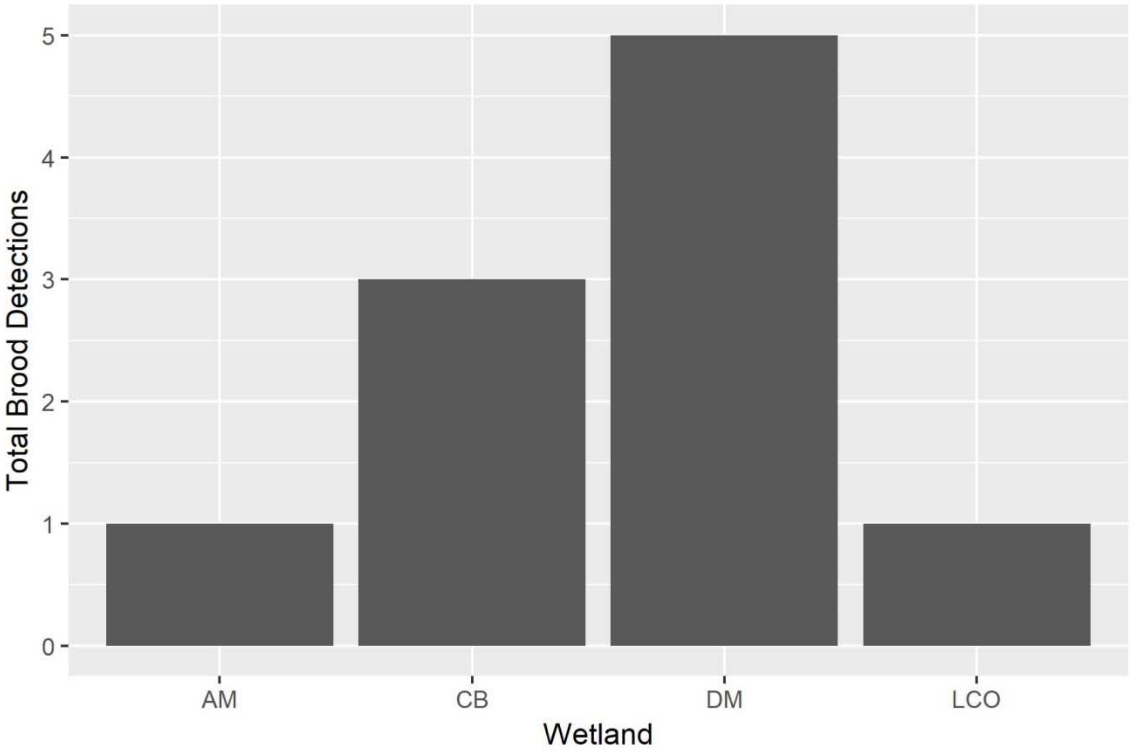

Figure 34: Distribution of waterfowl broods (excluding Canada Goose) among wetlands of the youngest age class (1a).

7.6 Temporal and Spatial Variation in Bald Eagle and Osprey Productivity

Here we summarize the observed annual variability in productivity for Bald Eagle and Osprey at Revelstoke Reach.

7.6.1 Methods

Data for analysis (Section 4.2.4) was limited to nests with known outcomes, classified either as 'successful', or 'failed'. As with other datasets, we elected to exclude 2008 from analysis because of unreliable observations from that year. In 2014 surveys were expanded to include Beaton Arm to provide a control against which effects of Revelstoke Reach could be measured. However, for this analysis, Beaton Arm nests were excluded.

From the selected data, we calculated the number of nesting attempts, the number of successful nests, and the number of failed nests for both species. We also calculated the annual percent success by dividing the number of successful nests by the number of nesting attempts, thus providing several metrics to measure productivity.

Spatial variability in productivity was considered for both Bald Eagle and Osprey. We hypothesized that nesting on east versus west shoreline may affect productivity due to proximity to aquatic foraging areas. To examine this, nests ($n = 43$, 16 Bald Eagle and 27 Osprey nests) were assigned to the shore they were situated on, 'east' or 'west' ($n_E = 10$, $n_W = 33$). The one-time maximum number of young fledged from each nest for the duration of the nest's existence (between discovery and destruction, or the end of the project) was used as the measure of success. The dataset for analysis thus included nest identifier, shore and the maximum number of young fledged for each nest. Data were examined graphically, and then analyzed using an ANOVA to determine if there was a statistically significant difference in the maximum number fledged from each nest depending on the shore the nest was situated on.

7.6.2 Results

Over the course of the study, 27 Osprey nests and 16 Bald Eagle nests were monitored, with 162 outcomes determined.

Annual productivity of Bald Eagle and Osprey varied considerably (Table 7-2). Bald Eagle were resilient breeders, producing between 0.6 – 1.7 young per nest, from between 2 and 7 active nests each year. Osprey consistently made more nesting attempts but produced fewer young than Bald Eagle. Osprey produced between 0.14 – 1.3 young per active nest, from between 7 – 12 active nests each year. Average productivity over the course of the study was 0.93 for Bald Eagle and 0.63 for Osprey.

Spatially, Bald Eagle and Osprey nests were distributed throughout Revelstoke Reach, but the majority of nests of both species were on the west side of the valley (Appendix 7.29). The maximum number of young fledged for both species pooled from a nest was highest on the east shore (Figure 12, Appendix 7.27). A one-way ANOVA found a graphically evident, but non-significant trend for the success of larger brood sizes on the east shore ($P_{\text{shore}} = 0.06$).

Table 7-2: Nesting results for Bald Eagle and Osprey over the 10 years of CLBMON-40. We excluded 2009 from the productivity analysis for both species as the number of fledged young was not consistently recorded that year.

Species Code	Year	Fledged	Nesting Attempts	Number Successful Nests	Productivity (young/nest)	Percent Successful Nests
BAEA	2008	3	2	2	1.5	1
BAEA	2009	-	4	3	0	0.75
BAEA	2010	12	7	7	1.71	1
BAEA	2011	4	6	4	0.67	0.67
BAEA	2012	3	3	3	1	1
BAEA	2013	3	5	3	0.6	0.6
BAEA	2014	3	4	3	0.75	0.75
BAEA	2015	4	5	3	0.8	0.6
BAEA	2016	12	7	7	1.71	1
BAEA	2017	3	5	2	0.6	0.4
OSPR	2008	1	7	1	0.14	0.14
OSPR	2009	11	9	7	1.22	0.78
OSPR	2010	10	12	6	0.83	0.5
OSPR	2011	6	7	4	0.86	0.57
OSPR	2012	2	8	2	0.25	0.25
OSPR	2013	2	7	1	0.29	0.14
OSPR	2014	9	10	4	0.9	0.4
OSPR	2015	13	10	7	1.3	0.7
OSPR	2016	3	9	2	0.33	0.22
OSPR	2017	2	9	1	0.22	0.11

7.6.3 Discussion

In Revelstoke Reach, Osprey forage in moving water (the Columbia River) or in separate wetlands when water levels are low. When the drawdown zone is submerged by the ALR, these available foraging habitats change dramatically as river, wetland, and grassland features are submerged, likely causing dispersed or redistributed prey over larger areas and deeper waters. The drawdown zone is very different near Nakusp, providing lake foraging only, and the metamorphoses of habitat caused by reservoir operations is far less extreme. It is likely that reservoir operations affect Revelstoke Reach Osprey more than Nakusp Osprey. We find it improbable that direct impacts of rainfall to Osprey productivity (i.e., nestling mortality caused by exposure to elements), would vary considerably among study sites; however, the effect of rainfall on productivity could also vary regionally, if mediated through impacts to foraging efficiency (Grubb 1977). Rainfall can influence water turbidity, temperature, flows, and depth – all of which could potentially influence the foraging efficiency of Osprey – but the changes to foraging conditions caused by rainfall likely varies among watersheds and would be influenced by river regulation.

7.7 Productivity Monitoring of Short-eared Owl and Northern Harrier

This analysis summarizes the exploration of factors which are likely to influence Short-eared Owl and Northern Harrier decisions to nest in the drawdown zone.

7.7.1 Methods

Both Short-eared Owl and Northern Harrier nest on the ground (Macwhirter and Bildstein 1996, Wiggins et al. 2006) and locating nests of either species is challenging. Details of nest searching methods have been described previously (Cooper Beauchesne and Associates 2017b). During the 10 years of the study, nesting occurred sporadically (Section 4.2.5). We elected to assess whether annual climatic conditions affected the probability of nesting, as in natural systems that is the most likely mechanism by which prey populations are influenced, and thus also nesting (Phelan and Robertson 1978, Village 1987, Korpimaki and Norrdahl 1991, Keyes 2011). We also considered reservoir operations, because we theorized that prey populations in the drawdown zone are likely modulated by annual inundation of habitat. We assessed the response of nesting from conditions during the preceding winter – minimum temperature, average temperature, and maximum depth of snow, and the maximum level of the Arrow Lakes Reservoir during the previous summer.

These variables were chosen as they reflect known influences on voles' reproductive cycles. A high maximum reservoir elevation could predict nesting because the high water would likely exterminate the vole population until late in the breeding season when population growth is slower; in contrast, a low maximum reservoir level would allow the vole population to grow via prolonged population expansion time (Negus et al. 1977). The remaining variables were related to climate data from the preceding winter, which we included because the vole population may have been impacted by winter severity (Aars and Ims 2002; Imholt et al. 2011). We examined "snow", which was the cumulative depth (in cm) of snowfall recorded by the City of Revelstoke. Finally, minimum and average temperatures represented the lowest and average temperature reached during the winter (November through March), respectively.

We subset the data to only examine Short-eared Owl for this analysis as the dataset was more robust than for Northern Harrier. However, these species inhabit the same niche, so conclusions drawn from Short-eared Owl data analysis can be applied to Northern Harrier.

Data were too sparse to consider fitting multivariate regressions. The four univariate models were compared using AICc (Burnham and Anderson 2002), and models with ΔAICc ≤ 2 were considered to have strong support (Arnold 2010).

Data from our annual surveys was supplemented with two records of nesting prior to our study (2001 and 2002) to give 11 years where nesting status was known. To assess predictors of nesting among years, we applied a series of univariate logistic regressions; one for each of four predictors: maximum elevation of the ALR in the previous year (max_elev), minimum temperature in the preceding year (min_temp), average temperature of the preceding winter (ave_temp), and snow depth (snow).

7.7.2 Results

The maximum level of the ALR in the previous year was the best predictor of whether Short-eared Owl would attempt to nest the following spring (AIC = 15.82, P = 0.14), followed by the maximum snow depth the previous winter (AIC = 17.26, P = 0.11).

Table 7-3: Univariate models examined to describe the factors affecting the settlement of Short-eared Owls in the drawdown zone.

Model	beta	p.val	AICc
Maximum Reservoir Level	-0.76	0.14	15.82
Snow Depth	-0.01	0.11	17.26
Average Temperature	0.56	0.39	19.86
Minimum Temperature	0.14	0.41	19.86

Examining the effect of maximum reservoir level on nesting does not result in a statistically significant relationship, yet the effect in shown in Figure 35 from a small sample size suggests that the reservoir likely influences nesting decisions by Short-eared Owls.

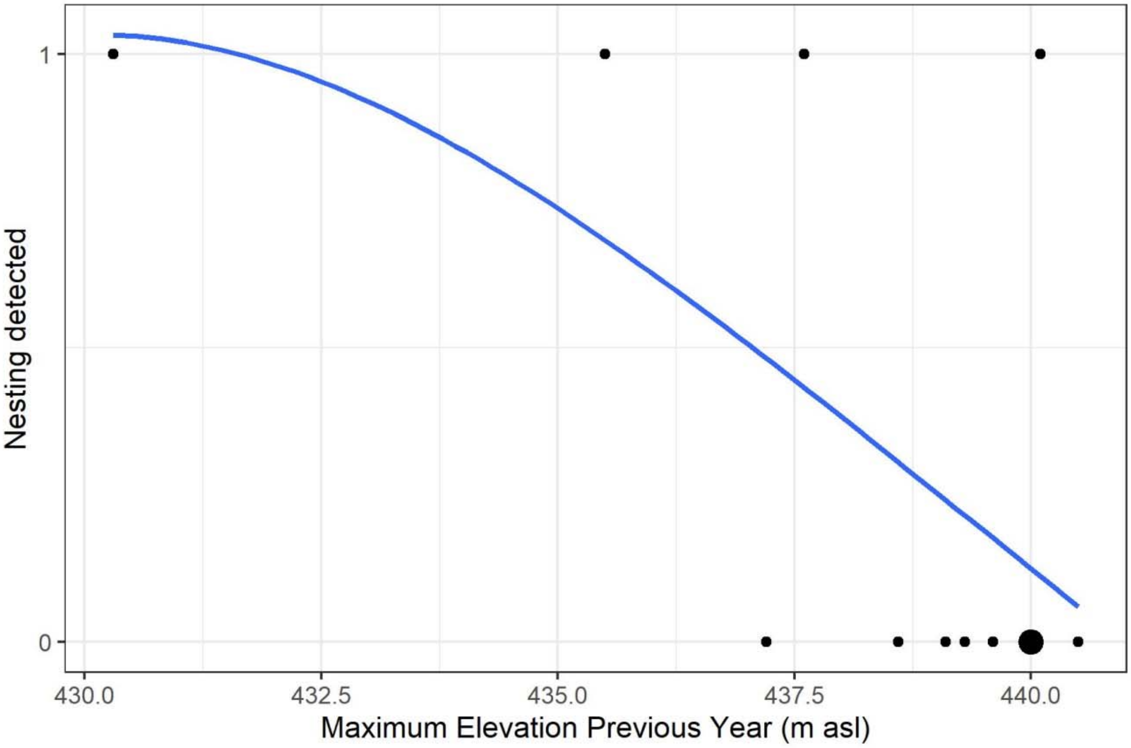

Figure 35: Evidence of nesting (1 = yes, 0 = no) as a function of the previous year's maximum reservoir level. The blue line is a loess regression line illustrating the reduction in nesting with high reservoir levels in the previous year.

7.7.3 Discussion

None of the models were statistically significant, but given the small sample size and what we consider as a biologically significant result, we feel these results suggest there may be a reservoir mediated effect on decisions by Short-eared Owls (and likely Northern Harriers) to settle in the subsequent nesting season. While vole populations were not studied, their population dynamics are known to be affected by environmental conditions (Negus et al. 1977). Thus, it is likely that the combination of weather and reservoir are mediating vole populations, and by extension birds of prey which depend on them.

7.8 Nest Flooding Impacts for Waterbirds

Nest flooding is the most acute impact of reservoir operations on waterbirds. We examined the nest data from CLBMON-36 (Craig and Gill 2020). We specifically looked at CLBMON-36 nest monitoring data for ground-nesting waterbird species, which are most exposed to nest flooding.

7.8.1 Methods

Nesting data from the CLBMON-36 10 year database were extracted for the following species: Mallard (n = 86), American Wigeon (n = 47), Spotted Sandpiper (n = 76), Killdeer (n = 78), Wilson's Snipe (n = 40) and Wilson's Phalarope (n = 11). These species represent those ground-nesting birds which are susceptible to nest flooding, and nest throughout the study area.

We excluded Pied-billed Grebe from the analysis as they nest on floating islands (but were known to be susceptible to variations in reservoir elevation) and also excluded nests from the floating bog island in Montana Bay, as it moves up and down as the reservoir elevation changes and is not inundated. Short-eared Owl and Northern Harrier are also susceptible to nest flooding and are addressed in Section 5.6. Detailed methods and results on the examination of reservoir operations on Short-eared Owl and Northern Harrier can be found in (Cooper Beauchesne and Associates 2016b p. 8).

These nesting data were joined to reservoir elevation data and the following were calculated:

- elevation of the nest
- date of first egg laid in the nest (when known)
- reservoir elevation on the date the nest was found
- reservoir elevation on the date the nest was terminated
- height of the nest above the reservoir elevation on the day it was found
- height of the nest above the reservoir elevation on the day the nest terminated.

Nest flooding depends not only on position in the drawdown zone, but also timing of nesting, and filling of the reservoir. Date of first egg was examined for each of the vulnerable species of waterfowl and shorebirds. Date of first egg for waterfowl was collected on 27 nests (14 Mallard, six Teal sp.[7], seven American Wigeon), and for shorebirds 32 nests with date of first egg were examined (22 Killdeer, and 10 Spotted Sandpipers). Date ranges of first egg laid in a nest are shown in Table 7-4.

The proportion of known outcomes for each bird type (shorebird and waterfowl) was calculated by dividing the number of outcomes by the total number of known outcomes.

Susceptibility to flooding was assessed by subsetting the data further to include only those species with known date of first egg, which is used as a measure of the date of nest initiation.

7.8.2 Results

Nesting waterfowl and shorebirds generally situated their nests at low elevations in the drawdown zone with Killdeer having the lowest nest in the data (433.1 m ASL).

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[7] Green-winged Teal, Blue-winged Teal and Cinnamon Teal were grouped as 'Teal sp.' because so few nests for those species were found, and they have similar nesting phenologies.

Shorebirds generally established nests in more risky settings – with their nests being distributed more narrowly near the reservoir shoreline (Figure 36).

The timing and elevations of waterbird nests (Table 7-4) had considerable potential for interactions with reservoir operations (Figure 37), which was also shown empirically by a substantial proportion of nests lost to reservoir operations (Table 7-5).

Outcomes of the nests examined is shown in Table 7-5. For species considered here, reservoir operations accounts for a relatively low proportion of nest mortality in waterfowl (15% of nests with known outcome failed by reservoir operations). Shorebirds experience a higher proportion of nest loss due to reservoir operations (36% of known outcomes failed due to reservoir operations. For shorebird and waterfowl species examined here, nest success was 43% and 51% respectively.

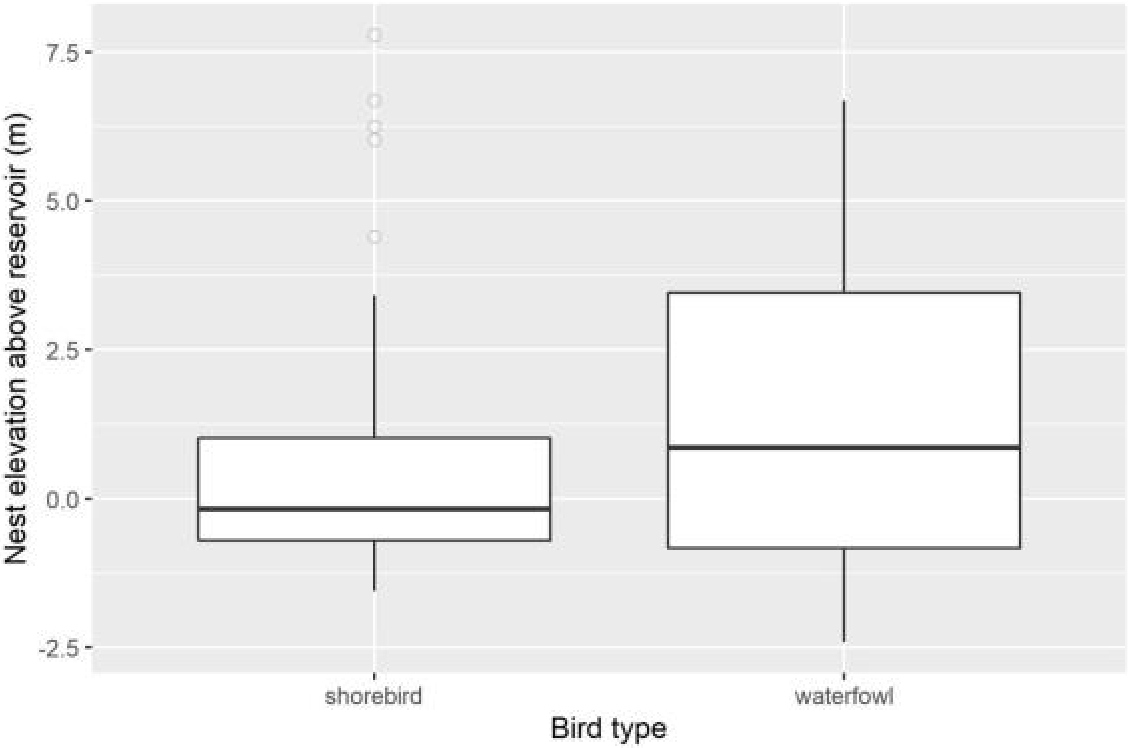

Figure 36: Height above the reservoir elevation each type of bird examined situates their nest. Elevation represents the height above water when the nest was found.[8]

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[8] This figure shows some nests situated below the elevation of the reservoir at the time the nest was found. These negative values are a result of errors in the digital elevation model.

Table 7-4: Date ranges for nest initiation for vulnerable species of waterfowl and shorebirds.

Species	Earliest date of first egg	Latest date of first egg	Nesting duration (days)	Nest elevation range
American Wigeon	June 9th	June 20th	26	435.75 - 439.22
Killdeer	May 19th	May 27th	25	434.45 - 436.97
Mallard	June 3rd	June 12th	28	434.63 - 439.77
Spotted Sandpiper	June 9th	June 16th	21	434.88 - 439.54
Teal sp.	June 11th	June 19th	23	438.49 - 438.9

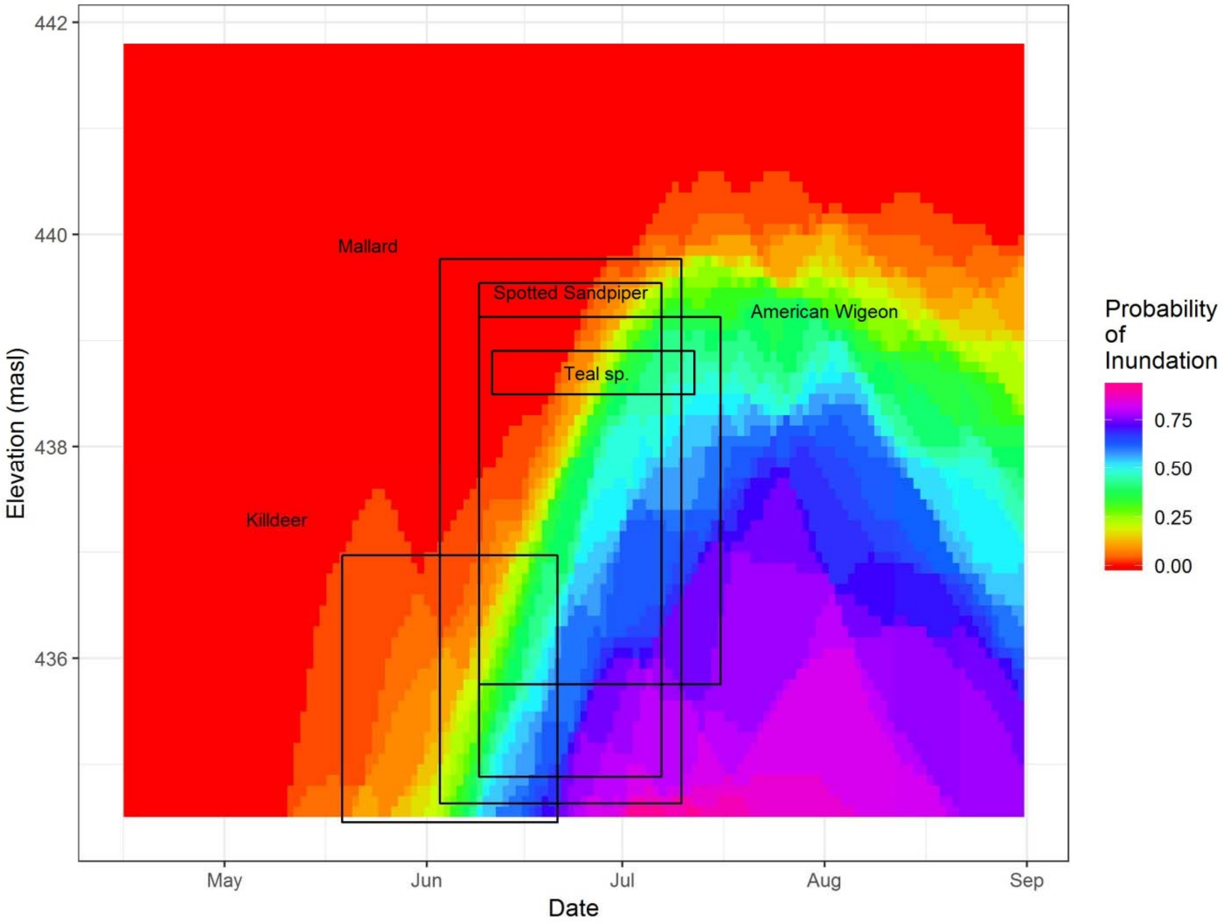


Figure 37. Rectangles for each of five waterbird species bound the highest and lowest nest elevations, the earliest clutch initiation dates, and the latest date of hatching (as per Table 7-5). The probability of reservoir inundation is displayed by coloured pixels, which is calculated from historic operation data from the Arrow Lakes Reservoir.

Table 7-5: Proportion of each of the known outcomes for nests of each bird type.

Bird Type	Nest Outcome	Number of Outcomes	Proportion of Outcomes
shorebird	Predation	34	0.20
	Reservoir operations	61	0.37
	Successful	72	0.43
waterfowl	Predation	50	0.33
	Reservoir operations	24	0.16
	Successful	76	0.51

Table 7-6: Proportion of known nest outcomes for the two most common shorebirds nesting in the study area.

Species	Outcome	Count of Outcomes	Proportion of Outcomes
Killdeer	Predation	15	0.25
Killdeer	Reservoir operations	19	0.32
Killdeer	Successful	25	0.42
Spotted Sandpiper	Predation	2	0.03
Spotted Sandpiper	Reservoir operations	32	0.48
Spotted Sandpiper	Successful	33	0.49

7.8.3 Discussion

The low elevation substrates which are often selected by shorebirds are flooded early, but the nesting phenology of some shorebirds (Killdeer) reduces this impact slightly due to their early nest initiation (Jackson and Jackson 2000, Craig and Gill 2020). Spotted Sandpipers initiate nests later than Killdeer, and are more susceptible to nest flooding (Oring et al. 1997, Craig and Gill 2020) (Table 7-6). Waterfowl initiate nests slightly higher above the shoreline than shorebirds which is reflected in their lower rate of failure due to reservoir operations (Table 7-5).

7.9 The influence of reservoir operations on the distribution and abundance of shorebirds in Revelstoke Reach

Disentangling seasonal effects from reservoir elevation effects requires accounting for species-specific migration patterns, and data are generally lacking for most species. Here total shorebird abundance and diversity are plotted against reservoir elevation on each survey occasion.

7.9.1 Methods

Data from land-based and boat-based shorebird surveys was combined to form a dataset of complete coverage of the study area (Section 4.2.3). Data were subsetted to include only those stations consistently surveyed during the study period, as well as stations representing biophysical attributes which were considered important for shorebirds. Shorebird data from 2008 was excluded due to incompleteness.

To examine trends as a function of reservoir operations, all species were pooled and analyzed together to create two metrics per survey: total shorebird abundance and total shorebird diversity.

7.9.2 Results

Generally, the reservoir was near its annual maximum elevation in the hydrograph when shorebird surveys commenced in July each year, and as the migration advanced, the reservoir typically decreased in elevation (Figure 2).

Plotting abundance against reservoir levels shows that larger counts of shorebirds were made when the reservoir was relatively low (top panel, Figure 38). A similar pattern was observed for shorebird diversity (bottom panel, Figure 38). However, this trend may be an artifact of the data, whereby only two years (2015, 2016) were sampled when the reservoir was below 430 m during migration. The majority of surveys in other years can be seen as a multi-coloured point cloud on the right side of the x axis.

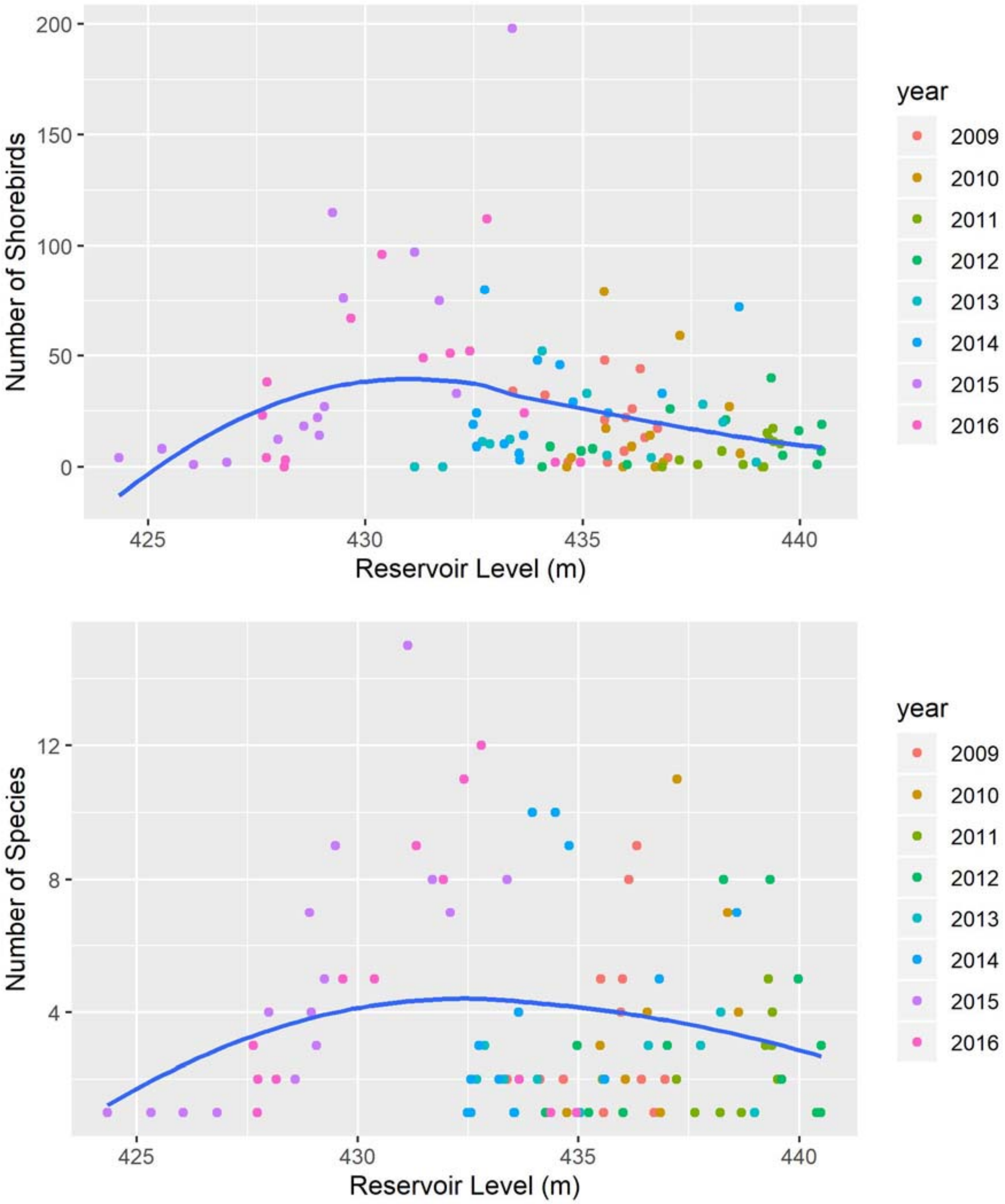


Figure 38: Reservoir level during each survey is plotted on the x axis. The total abundance of shorebirds is plotted in the upper graph whereas the species diversity is plotted in the lower graph. The colour of the points represents the year of the survey. Loess smoothing lines are plotted to illustrate trends in abundance of birds at different water levels. Year of survey is colour coded to illustrate different conditions among years.

7.9.3 Discussion

Complex statistical analysis is required before conclusions can be drawn regarding how reservoir elevation affects shorebirds, and extreme care must be taken when examining the results provided here.

Water levels due to reservoir operations has a profound effects on the distribution of shorebirds due to the changing position and character of shorelines. There are many factors that make it very challenging to quantify how shorebird abundance depends on reservoir elevation including: (1) the shifting distribution of shorebirds based on shifting shorelines; (2) the overall low abundance; (3) exceptionally sporadic and unpredictable occurrences of migrating shorebirds; (4) differing timing of migration depending on species; (5) potential non-linearity of both seasonal and elevation-related effects; and in the case of Spotted Sandpipers, (6) unclear distinction between observations of breeding versus migrating shorebirds early in the migration season. Even if there were more data, there is a great challenge in disentangling seasonal pattern related to migration intensity versus seasonal patterns related to the hydrograph.

It is also likely that the counting process was affected by reservoir elevation; for example, at very low reservoir elevations in 2015 and 2016, we were unable to survey some high-value habitat around the Akolkolex River due to access. Likely we missed shorebirds in these years.

There were only two years of the study period saw reservoir levels below 430 m during migration (2015 and 2016). Lower elevations are under-represented compared to mid-elevations which were more often sampled. There is better representation across time periods at the mid to upper elevations.

While the data were initially analyzed statistically for this report, those results are not presented. The various complexities of the rather sparse dataset were challenging to deal with, and none of the early results were robust enough to present in this document, given resources available at the time. There does remain potential to analyze the data further. We recommend considering only species that are most well-represented, but care must be taken to control for time of year (e.g., with a smoothing function).

7.10 Do water levels influence brood counts?

The question of whether reservoir operations influence productivity can be addressed by contrasting brood count data. Brood survey results are an index of waterfowl productivity, but care must be taken in interpreting such data because brood detections are likely to correspond with reservoir operations, which may be hard to disentangle from effects on productivity. A conclusive analysis of brood count data was performed after eight years of data had been gathered in the Year 8, 2015 annual report (Cooper Beauchesne and Associates 2016b), which is adapted for presentation here for reader convenience.

7.10.1 Methods

Early examination of brood count data in the Year 6 annual report showed that a seasonal effect altered the relationship that could be seen between brood counts and reservoir operations: a low brood count was observed in years when ALR had aggressive filling, but only later in the brood rearing season (Cooper Beauchesne and Associates 2013b). In 2015 brood count data were re-analyzed, making use of the previous findings to guide our approach. That analysis included 8 years of data

The approach used was to calculate the average count of broods observed in the late part of the brood monitoring period (week 25 to 31 in the year) when brood counts are maximal. This generated eight data points (average brood counts) which were analyzed against the maximum reservoir elevation observed each year. A Poisson distribution was used to model random scatter around the regression function using a quasi-Poisson model, which makes an adjustment for minor levels of over-dispersion.

7.10.2 Results

The quasi-Poisson regression showed a strong negative relationship between maximum reservoir pool each year, and the average number of duck broods observed per survey during the late part of the brood rearing season ($P = 0.02$, McFadden’s $r^2 = 0.58$).

7.10.3 Discussion

A negative relationship between reservoir elevation and our brood counts was detected. As this analysis (and project) is correlative in nature, it is possible that other factors are the true causation; for example, it could be that weather is predictive of both reservoir operations and duck productivity. It is also possible that broods are simply harder to count when reservoir elevations are higher; for example, if brood rearing habitats are selected in regions that are not monitored, or if brood rearing switches from wetlands to flooded shrubs. Nonetheless, this evidence does correspond with a known impact of nest flooding, and the result is an important piece of evidence to consider.

An alternate approach to ascertaining how reservoir operations impact waterfowl productivity would be to focus on survivorship of waterfowl nests, as a function of reservoir operations. This could be achieved using data from CLBMON-36.

7.11 The influence of reservoir operations on the distribution and abundance of waterfowl in Revelstoke Reach

Here the effect of reservoir elevation on waterfowl abundance and distribution was assessed using aerial waterfowl surveys.

7.11.1 Methods

Aerial survey data were used as they allowed a complete census of the entire study area (Section 4.2.2).

Two analyses were performed: (1) analysis of how water depth affected overall annual abundance during fall migration; and (2) analysis of how water depth affected individual sites on each survey occasion based on their habitat type.

For both analyses the focus was on ecology of 'waterfowl', however Canada Goose data were excluded. Canada Goose are generally considered to be overabundant in the region and elsewhere in BC. Due to their sheer numbers and unique habitat requirements, Canada Goose data would obscure results of the other waterfowl species which were the primary interest.

For both analyses, seasonality needed to be controlled-for due to the extreme variability caused by migrational progression (see Section 7.1). However, due to the small sample size, seasonality could not be accounted for using statistical controls relying on variability native to the aerial survey dataset. To control for seasonal effects, the daily migration intensity estimates derived from numerically robust Land-based waterbird data were assigned to the aerial survey data, which was used to statistically control for seasonal state on each aerial survey occasion, by inclusion as the covariate ‘Seasonality’. Methods for deriving Seasonality are outlined in Section 7.1.

Analysis 1: overall abundance

The first analysis only considered aerial survey data collected during the fall migration (n = 27 surveys). Fall data were selected because the reservoir had a greater range elevation during the fall migration, whereas the study area was generally not inundated during the spring migration. By excluding data from the spring migration, variation caused by migration character (e.g., bird population and behavioural differences before and after the breeding season) and habitat states (e.g., biomass of vegetation) were also controlled-for by design.

The response variable in the analysis was the total number of waterfowl detected on each survey. The influence of Year and Reservoir Elevation on waterfowl abundance were assessed using a General Linear Model (GLM, i.e., multiple regression) with Year entered as a fixed factor, and with Reservoir Elevation and Seasonality entered as numeric predictors.

Analysis 2: habitat distributions

In the second analysis, all aerial survey data were utilized (Section 4.2.2, n = 45 complete surveys) to inform how the distribution of waterbirds shifted as a function of site-specific water depth.

Aerial survey data was analyzed by considering the probability of use by waterfowl at the polygon level (Section 4.2.2, n = 130 polygons). On each survey, the presence of waterfowl was determined at each polygon.

On each survey occasion, the water depth was calculated for each polygon by subtracting the average terrain elevation of the polygon (based on a digital elevation model with 5m horizontal resolution) from the current reservoir elevation, and adjusted to zero, when reservoir elevations were lower than the polygon elevation.

The probability of waterfowl being detected in polygons was analyzed using a binomial generalized additive mixed model (GAMM). Polygon ID was entered as a random effect. Habitat Strata (five broad habitat categories; Section 4.2.2) was entered as a categorical fixed effect. Water depth was entered as a continuous numeric predictor variable modelled as a smoothing variable, separately for each habitat strata. Seasonality was included as a covariate in the model to account for intensity of migration.

7.11.2 Results

Analysis 1

The GLM of total abundance found no statistical differences among years (all $P > 0.3$), and no effect of reservoir elevation ($P = 0.7$). The covariate Seasonality approached statistical significance ($P = 0.073$) with a positive relationship with waterfowl abundance as expected.

Analysis 2

The Analysis 1 GAMM with polygon as a random effect were fitted to binomial data, with each of the strata used to predict the presence of waterfowl at different reservoir levels ($n_{grass} = 1906$, $n_{shrub.forest} = 403$, $n_{channel} = 2029$, $n_{unvegetated} = 909$, $n_{wetland} = 1467$). The movement from preferential wetland habitat to inundated terrestrial habitat as water depth increases reflects what is known about foraging niches of dabbling waterfowl (Figure 39) (Baschuk et al. 2012).

7.11.3 Discussion

There was no evidence that waterfowl abundance differed greatly among years during the fall migration.

While abundance did not vary with reservoir elevations, the probability of finding waterfowl at particular sites was very much influenced; however, the impact of water depth at particular sites differed depending on habitat type. Notably, waterfowl were increasingly less likely to be detected at wetlands as inundation depth increased, and the suitability of grasslands was maximal when inundated with shallow water.

There are numerous ways to examine how waterfowl abundance is influenced by reservoir operations, seasonality and annual effects. These results based on aerial census data were relatively robust because they account for waterfowl distribution rearrangements that may be caused by changing habitat conditions; however, they lack precision that can gained via large sample sizes. It is important to keep all limitations in mind, and to consider results gained from other approaches.

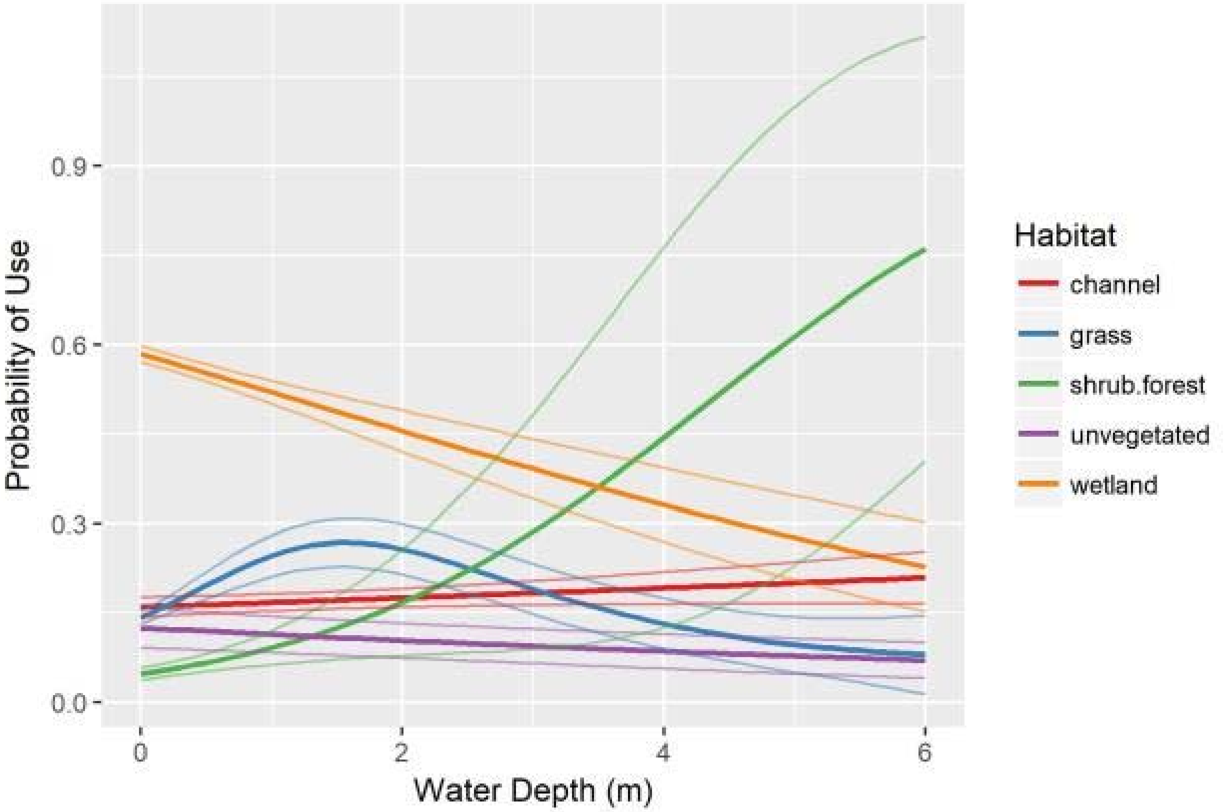


Figure 39. The probability of use by ducks of inundated habitat plotted against the depth of inundation. The X axis is how deeply inundated habitat is, based on reservoir level and digital elevation values for each waterbird observation.

7.12 Core shorebird wetlands

Shorebird Wetland	Location	Number of Survey Stations
11 Mile Eddy	within reservoir	1
9 mile	within reservoir	1
9 Mile South	within reservoir	3
Airport West	within reservoir	3
biophysical station	within reservoir	12
Blanket	within reservoir	10
Cartier Bay	within reservoir	7
Downie Marsh	within reservoir	3
Griffith's Creek	within reservoir	1
Hall's Landing North	within reservoir	5
Illecillewaet Ditch	above reservoir	1
Jordan River Mouth	above reservoir	1
Locks Creek Outflow	within reservoir	2
Machete Ponds	within reservoir	3
Montana Bay	within reservoir	2
Motherwell Channel	above reservoir	1
Wigwam	within reservoir	6

7.13 Annual results of land-based waterbird surveys.

Year	Number of Surveys	Annual Total Count of Waterbirds	Number of Species	Birds/Survey
2008	11	6975	43	634
2009	18	12214	48	678
2010	22	15355	49	698
2011	21	13313	43	634
2012	22	13136	38	597
2013	21	13708	44	653
2014	22	13768	40	626
2015	22	11386	43	518
2016	22	15809	41	719
2017	16	10646	37	665

7.14 Total cumulative count of waterfowl observations recorded during land-based waterbird surveys for each season surveyed. Winter surveys were discontinued after 2015.

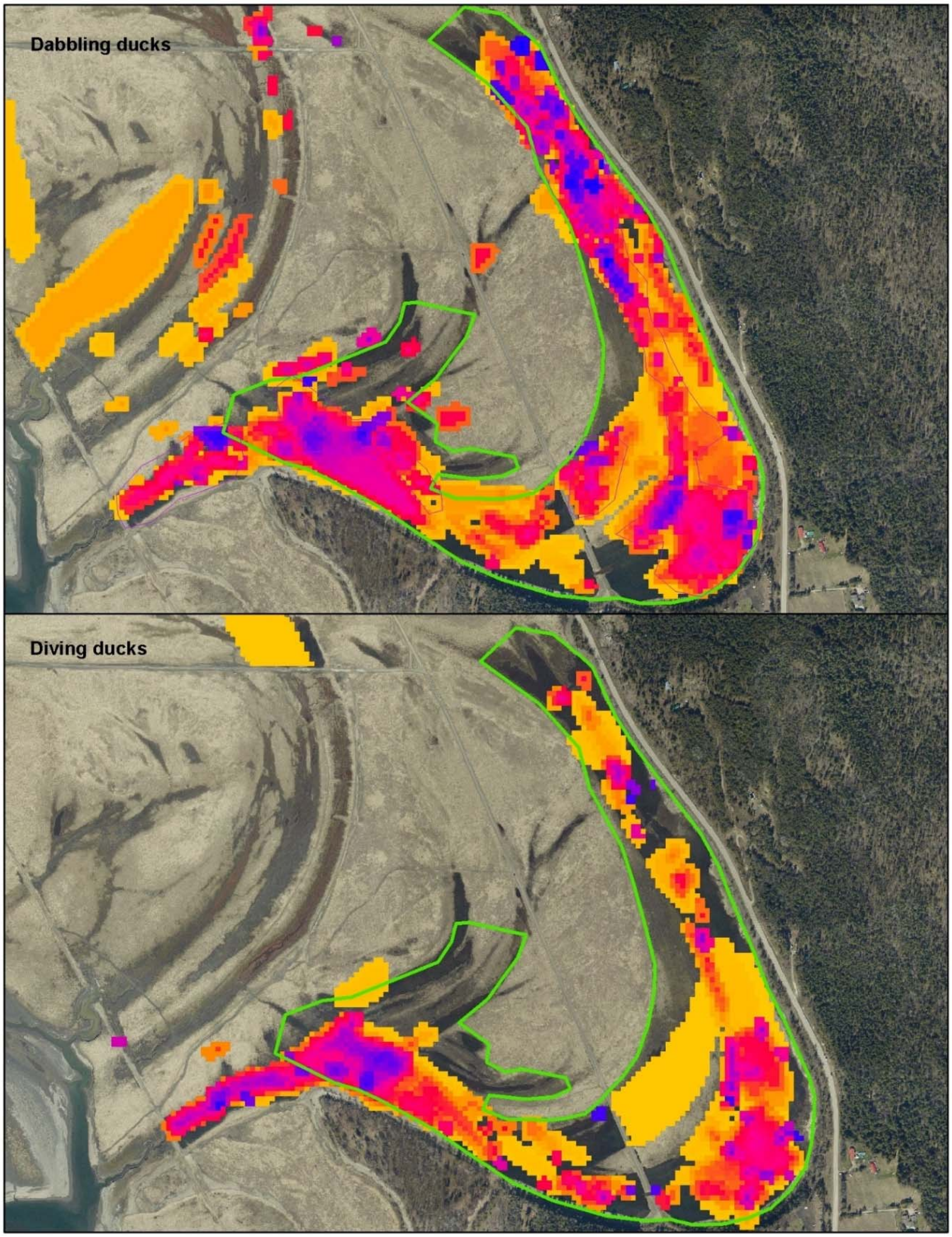
Common Name	Scientific Name	Winter	Spring	Brood	Fall
American Coot	*Fulica americana*	2534	1404	34	8566
American White Pelican	*Pelecanus erythrorhynchos*	0	2	0	0
American Wigeon	*Anas americana*	4577	11256	1507	17136
Barrow's Goldeneye	*Bucephala islandica*	134	250	3	10
Blue-winged Teal	*Anas discors*	1	245	61	192
Bufflehead	*Bucephala albeola*	714	840	15	278
Cackling Goose	*Branta hutchinsii*	0	0	0	4
Canada Goose	*Branta canadensis*	12513	15639	9302	25722
Canvasback	*Aythya valisineria*	10	16	1	33
Cinnamon Teal	*Anas cyanoptera*	0	192	38	0
Common Goldeneye	*Bucephala clangula*	712	385	3	25
Common Loon	*Gavia immer*	23	73	189	129
Common Merganser	*Mergus merganser*	1329	1985	312	417
Double-crested Cormorant	*Phalacrocorax auritus*	0	2	0	2
Eurasian Green-winged Teal	*Anas c. crecca*	0	1	0	0
Eurasian Wigeon	*Anas penelope*	1	31	0	3
Gadwall	*Anas strepera*	30	77	5	46
Goldeneye Sp	*Bucephala sp*	182	118	8	17
Greater Scaup	*Aythya marila*	0	76	3	3
Greater White-fronted Goose	*Anser albifrons*	2	0	6	0
Green-winged Teal	*Anas crecca*	1265	1697	97	2051
Hooded Merganser	*Lophodytes cucullatus*	325	104	21	619
Horned Grebe	*Podiceps auritus*	5	1	1	12
Lesser Scaup	*Aythya affinis*	2	112	3	43
Mallard	*Anas platyrhynchos*	4258	8403	1731	7796
Northern Pintail	*Anas acuta*	22	697	4	453
Northern Shoveler	*Anas clypeata*	25	532	29	247
Pacific Loon	*Gavia pacifica*	0	0	0	4
Pied-billed Grebe	*Podilymbus podiceps*	137	135	251	849
Red-breasted Merganser	*Mergus serrator*	0	0	1	0

Common Name	**Scientific Name**	**Winter**	**Spring**	**Brood**	**Fall**
Red-necked Grebe	*Podiceps grisegena*	21	12	6	61
Redhead	*Aythya americana*	58	16	2	22
Ring-necked Duck	*Aythya collaris*	41	2039	84	767
Ruddy Duck	*Oxyura jamaicensis*	16	26	0	13
Scaup Sp	*Aythya* sp	54	237	1	78
Snow Goose	*Chen caerulescens*	3	33	0	18
Surf Scoter	*Melanitta perspicillata*	0	162	0	3
Trumpeter Swan	*Cygnus buccinator*	131	64	2	7
Tundra Swan	*Cygnus columbianus*	64	97	0	33
Unidentified Duck	*Anatinae* (gen sp)	1046	2243	248	3531
Unidentified Grebe	-	11	0	1	13
Unidentified Swan	*Cygnus* sp	41	92	0	49
Unidentified Teal	*Anas* sp	311	6	3	1161
Western Grebe	*Aechmophorus occidentalis*	22	0	1	115
White-winged Scoter	*Melanitta fusca*	3	0	0	0
Wood Duck	*Aix sponsa*	0	122	350	575
	Totals	**30623**	**49422**	**14323**	**71103**

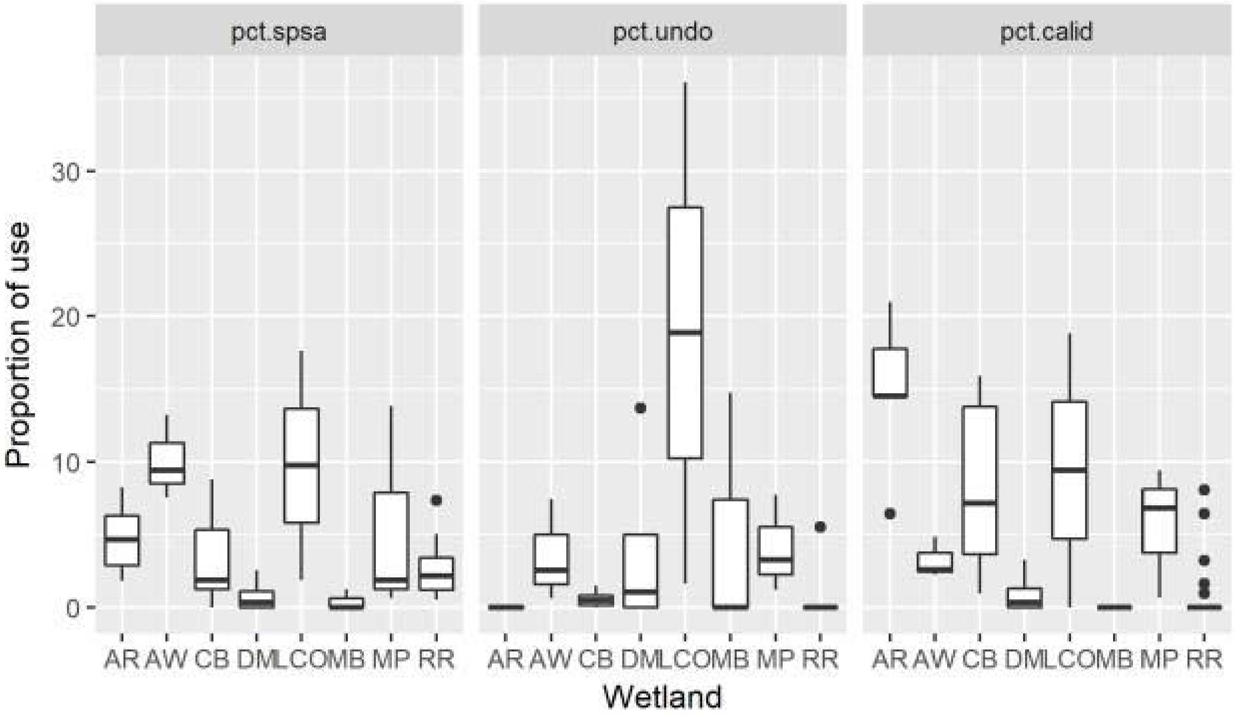
7.15 Total counts and proportions of each shorebird species detected on fall migration surveys in Revelstoke Reach.

Shorebird species	Count	Proportion of total
Baird's Sandpiper	10	0.4%
Dowitcher sp.	647	24.1%
Killdeer	242	9.0%
Least Sandpiper	78	2.9%
Pectoral Sandpiper	161	6.0%
Red-necked Phalarope	15	0.56%
Sanderling	5	0.19%
Semipalmated Plover	10	0.4%
Semipalmated Sandpiper	61	2.3%
Solitary Sandpiper	103	3.8%
Spotted Sandpiper	785	29.3%
Stilt Sandpiper	1	0.04%
Unknown Calidris Sandpiper	29	1.1%
Unknown Shorebird	86	3.2%
Western Sandpiper	23	0.9%
Wilson's Phalarope	3	0.1%
Wilson's Snipe	94	3.5%
Yellowlegs sp.	327	12.2%

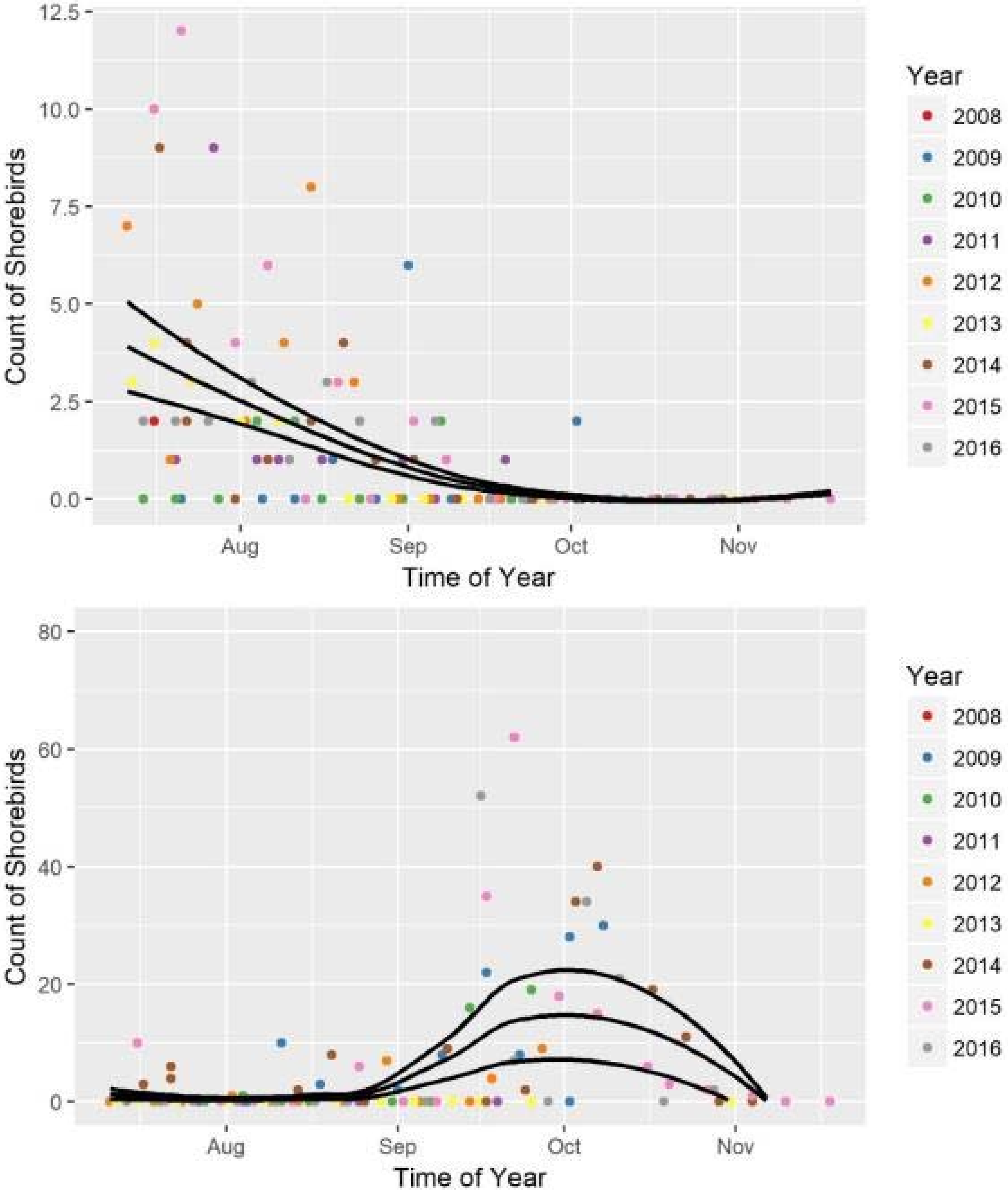
7.16 **Distribution of diving and dabbling ducks in Cartier Bay. Darker colours represent higher density. Diving ducks congregate in the deeper water at the west end of Cartier Bay, while dabblers select shallow habitat at the north end.**



7.17 Proportion of use among wetlands for the most commonly detected shorebirds. AR = Akolkolex River, AW = Airport West, CB = Cartier Bay, DM = Downie marsh, LCO = Locks Creek Outflow, MB = Montana Bay, MP = Machete Ponds, RR = Revelstoke Reach. Labels: pct.spsa = proportion of Spotted Sandpiper detections at each wetland, pct.undo = proportion of Dowitcher sp. detections at each wetland, and pct.calid = proportion of Calidris sp. sandpipers detected at each wetland.



7.18 Patterns of shorebird migration for the two most common shorebirds detected: Spotted Sandpiper (top) and Dowitcher spp. (bottom)



7.19 Plant species identified by wetland vegetation sampling for CLBMON-11B-4 at Airport Marsh and Cartier Bay.

Common Name	Scientific Name	Species Abbreviation	Wetland
bluejoint reedgrass	*Calamagrostis canadensis*	CALACAN	Airport Marsh
water sedge	*Carex aquatilis*	CAREAQU	Airport Marsh
lakeshore sedge	*Carex lenticularis*	CARELEN	Airport Marsh
Carex sitchensis	*Carex sitchensis*	CARESIT	Airport Marsh
blunt broom sedge	*Carex tribuloides*	CARETRI	Airport Marsh
common hornwort	*Ceratophyllum demersum*	CERADEM	Airport Marsh, Cartier Bay
Stonewort sp.	*Chara sp.*	CHARA	Airport Marsh, Cartier Bay
marsh cinquefoil	*Comarum palustre*	COMAPAL	Airport Marsh
common spike-rush	*Eleocharis palustris*	ELEOPAL	Airport Marsh
swamp horsetail	*Equisetum fluviatile*	EQUIFLU	Airport Marsh
scouring-rush	*Equisetum hyemale*	EQUIHYE	Airport Marsh
marsh horsetail	*Equisetum palustre*	EQUIPAL	Airport Marsh
hemp-nettle	*Galeopsis tetrahit*	GALETET	Airport Marsh
common mare's-tail	*Hippuris vulgaris*	HIPPVUL	Airport Marsh
tufted loosestrife	*Lysimachia thyrsiflora*	LYSITHY	Airport Marsh
Moss sp.	*Moss sp.*	Moss sp.	Airport Marsh, Cartier Bay
small-flowered forget-me-not	*Myosotis laxa*	MYOSLAX	Airport Marsh
Eurasian water-milfoil	*Myriophyllum spicatum*	MYRISPI	Airport Marsh, Cartier Bay
water smartweed	*Persicaria amphibia*	PERSAMP	Airport Marsh, Cartier Bay
reed canarygrass	*Phalaris arundinacea*	PHALARU	Airport Marsh
Kentucky bluegrass	*Poa pratensis*	POAPRA	Airport Marsh
water smartweed	*Persicaria amphibia*	POLYAMP	Airport Marsh, Cartier Bay
floating-leaved pondweed	*Potamogeton natans*	POTANAT	Airport Marsh, Cartier Bay
small pondweed	*Potamogeton pusillus*	POTAPUS	Airport Marsh, Cartier Bay
Richardson's pondweed	*Potamogeton richardsonii*	POTARIC	Airport Marsh, Cartier Bay

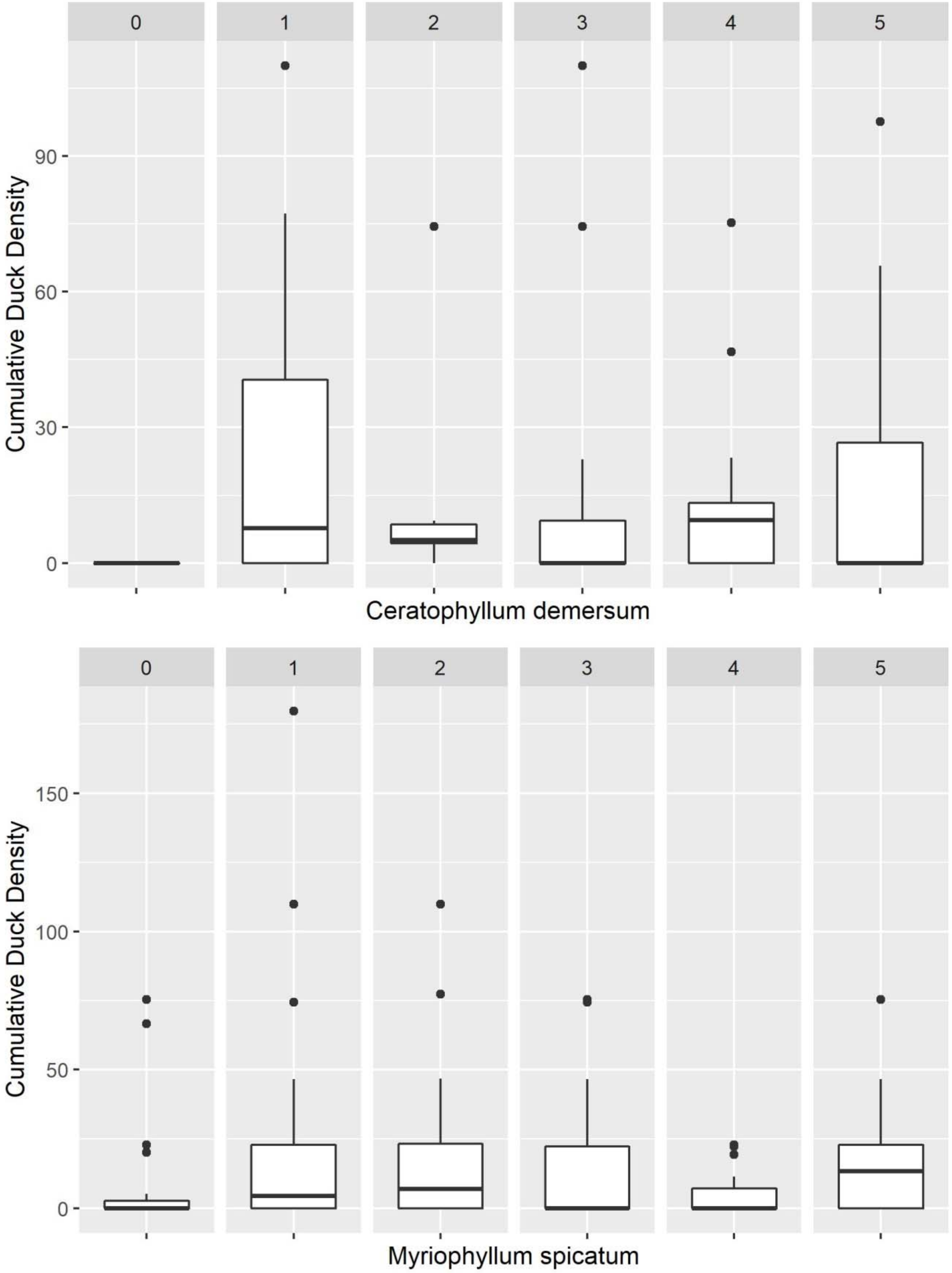
Common Name	Scientific Name	Species Abbreviation	Wetland
eel-grass pondweed	*Potamogeton zosteriformis*	POTAZOS	Airport Marsh, Cartier Bay
willow	*Salix sp.*	SALIXSP.	Airport Marsh
soft-stemmed bulrush	*Schoenoplectus tabernaemontani*	SCHOTAB	Airport Marsh
small-flowered bulrush	*Scirpus microcarpus*	SCIRMIC	Airport Marsh
hemlock water-parsnip	*Sium suave*	SIUMSUA	Airport Marsh
narrow-leaved bur-reed	*Sparganium angustifolium*	SPARANG	Airport Marsh
bur-reed	*Sparganium sp.*	Sparganium	Airport Marsh
small bur-reed	*Sparganium natans*	SPARNAT	Airport Marsh
common cattail	*Typha latifolia*	TYPHLAT	Airport Marsh
greater bladderwort	*Utricularia macrorhiza*	UTRIMAC	Airport Marsh, Cartier Bay
American vetch	*Vicia americana*	VICIAME	Airport Marsh

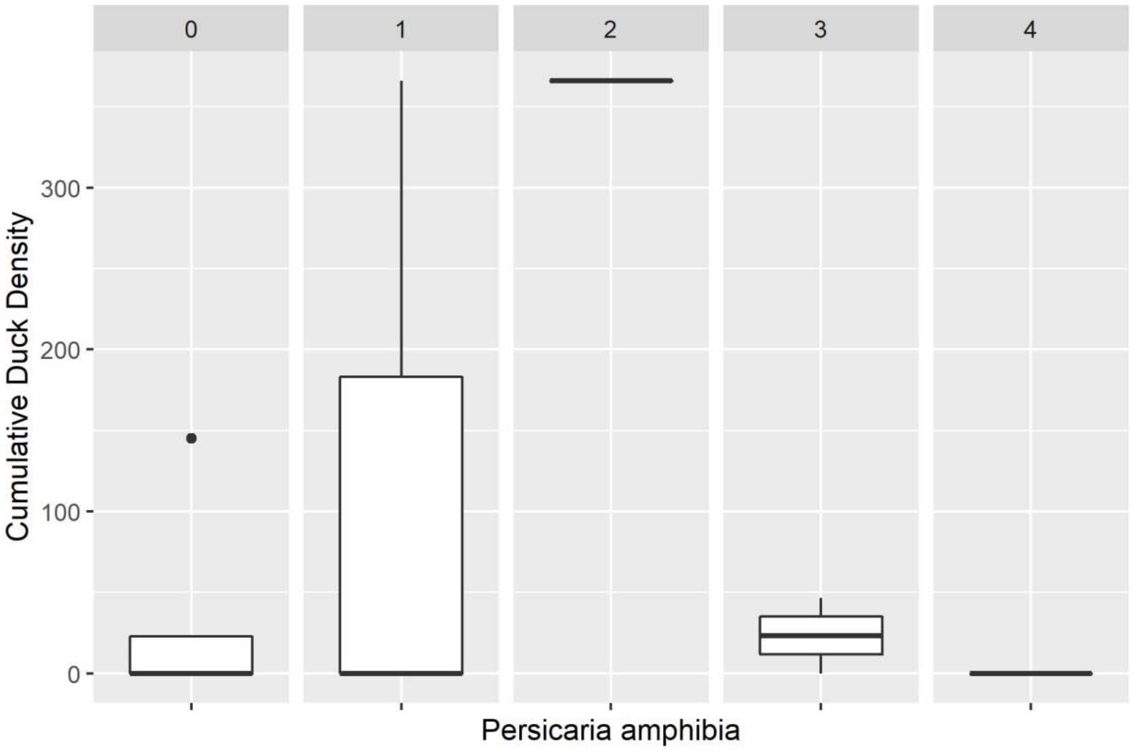
7.20 **Summary of macrophyte availability and associated density of waterfowl across CLBMON-11B-4 plots. "Total Plots" is the total number of plots where the macrophyte species was recorded. Total Plots is broken down across the two wetlands ("Location"). "Cumulative Density" is the cumulative density of waterfowl at the Total Plots (all surveys and plots combined). "Multi-year Density/Plot" is Multi-year Density divided by Total Plots, providing an average multi-year density of waterfowl observed at plots containing the macrophyte species.**

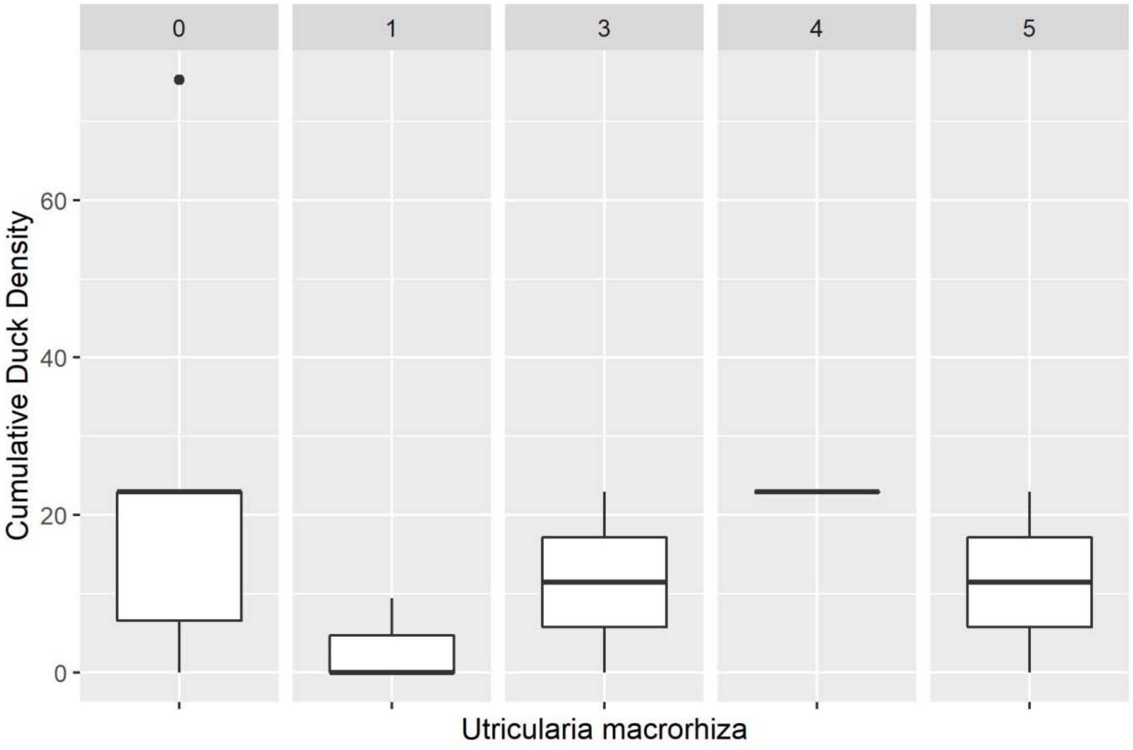
Scientific Name	Cumulative Density	Location		Total Plots	Multi-year Density/Plot
		Airport Marsh	Cartier Bay		
Calamagrostis canadensis	8.1	5	0	5	1.6
Carex aquatilis	492.8	9	0	9	54.8
Carex lenticularis	0.0	2	0	2	0.0
Carex sitchensis	0.0	1	0	1	0.0
Carex tribuloides	0.0	2	0	2	0.0
Ceratophyllum demersum	2049.9	23	25	48	42.7
Chara sp.	2308.1	33	24	57	40.5
Comarum palustre	103.1	3	0	3	34.4
Eleocharis palustris	0.0	1	0	1	0.0
Equisetum fluviatile	248.9	8	0	8	31.1
Equisetum hyemale	0.0	2	0	2	0.0
Equisetum palustre	22.9	1	0	1	22.9
Galeopsis tetrahit	0.0	1	0	1	0.0
Hippuris vulgaris	262.2	7	0	7	37.5
Lysimachia thyrsiflora	68.7	1	0	1	68.7
Moss sp.	365.9	3	1	4	91.5
Myosotis laxa	0.0	1	0	1	0.0
Myriophyllum spicatum	2752.6	35	23	58	47.5
Persicaria amphibia	2036.9	20	4	24	84.9
Phalaris arundinacea	736.1	19	0	19	38.7
Poa pratensis	0.0	1	0	1	0.0
Potamogeton natans	769.8	27	1	28	27.5
Potamogeton pusillus	3009.7	29	24	53	56.8
Potamogeton richardsonii	250.8	12	6	18	13.9
Potamogeton zosteriformis	81.3	5	5	10	8.1
Salix sp.	0.0	1	0	1	0.0
Schoenoplectus tabernaemontani	0.0	2	0	2	0.0
Scirpus microcarpus	104.4	5	0	5	20.9
Sium suave	45.8	1	0	1	45.8
Sparganium angustifolium	22.9	2	0	2	11.4
Sparganium natans	91.6	1	0	1	91.6

Sparganium sp.	68.7	2	0	2	34.3
Typha latifolia	274.7	4	0	4	68.7
Utricularia macrorhiza	499.2	12	1	13	38.4
Vicia americana	0.0	1	0	1	0.0

7.21 Trends in duck density as a function of the relative abundance of each macrophyte species at plots.



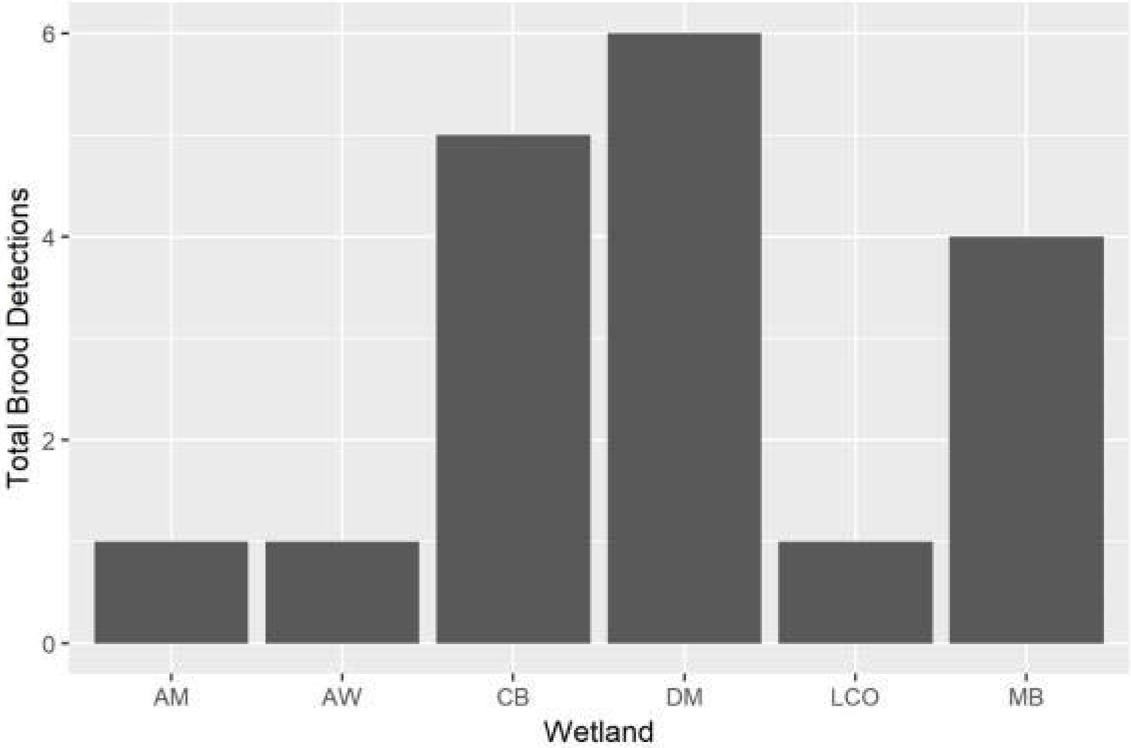

0
1
2
3
4
Cumulative Duck Density
300
200
100
0
Persicaria amphibia

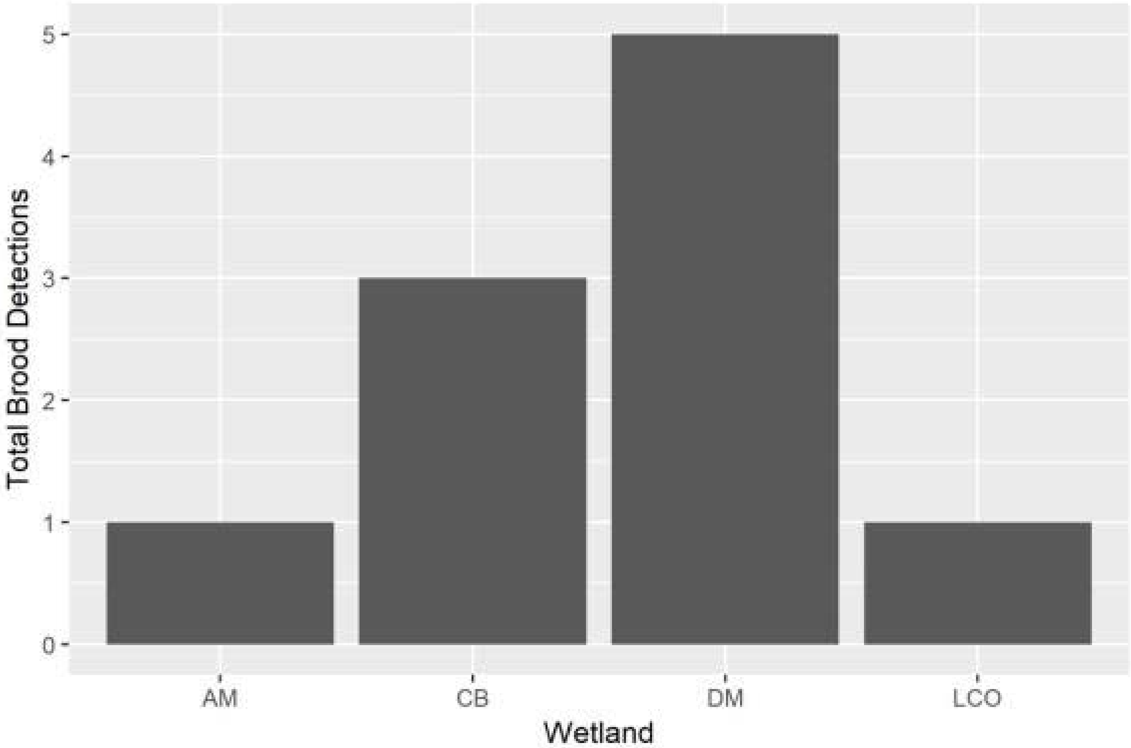

0
1
3
4
5
Cumulative Duck Density
60
40
20
0
Utricularia macrorhiza

7.22 Species detected with broods in the study area (RR: Revelstoke Reach, AM: Airport Marsh, AW: Airport West, CB: Cartier Bay, DM: Downie Marsh, LCO: Locks Creek Outflow, MB: Montana Bay, MP: Machete Ponds.

Species	Vulnerable?	RR	AM	AW	CB	DM	LCO	MB	MP	Total	
Canada Goose	No	8	49	42	98	0	67	132	0	396	67%
Common Merganser	No	4	0	3	8	0	1	3	0	19	3%
Wood Duck	No	0	15	0	0	3	2	5	0	25	4%
American Wigeon	Yes	0	17	3	9	20	2	10	8	69	12%
Mallard	Yes	4	1	1	9	21	7	5	8	56	10%
Northern Shoveler	Yes	0	0	0	0	0	0	1	0	1	0%
Pied-billed Grebe	Yes	0	8	0	0	0	0	0	0	8	1%
Ring-necked Duck	Yes	0	1	0	0	0	0	0	0	1	0%
Unidentified Duck	Yes	0	7	1	1	0	0	0	2	11	2%
Wilson's Phalarope	Yes	0	0	1	0	0	0	0	0	1	0%
Total	-	16	98	51	125	44	79	156	18	587	100%
Proportion at each wetland		3%	17%	9%	21%	7%	13%	27%	3%	100%	

7.23 **Total numbers of very young broods (age class 1a) detected at wetlands. Top chart is of all species, including Canada Goose and those species which are not at risk of nest flooding. Bottom chart shows only those species at risk of flooding.**





7.24 Shorebird species nesting in the Arrow Lakes Reservoir and their nest outcomes.[9]

Species	Fate	Number of Outcomes
Killdeer	Abandoned	1
	Failed by other means	1
	Predation	10
	Reservoir operations	4
	Successful	12
Spotted Sandpiper	Abandoned	4
	Failed by unknown means	1
	Predation	2
	Reservoir operations	11
	Successful	18
Wilson's Phalarope	Reservoir operations	1
	Successful	1
Wilson's Snipe	Abandoned	1
	Failed by other means	1
	Failed by unknown means	1
	Predation	11
	Reservoir operations	5
	Successful	37

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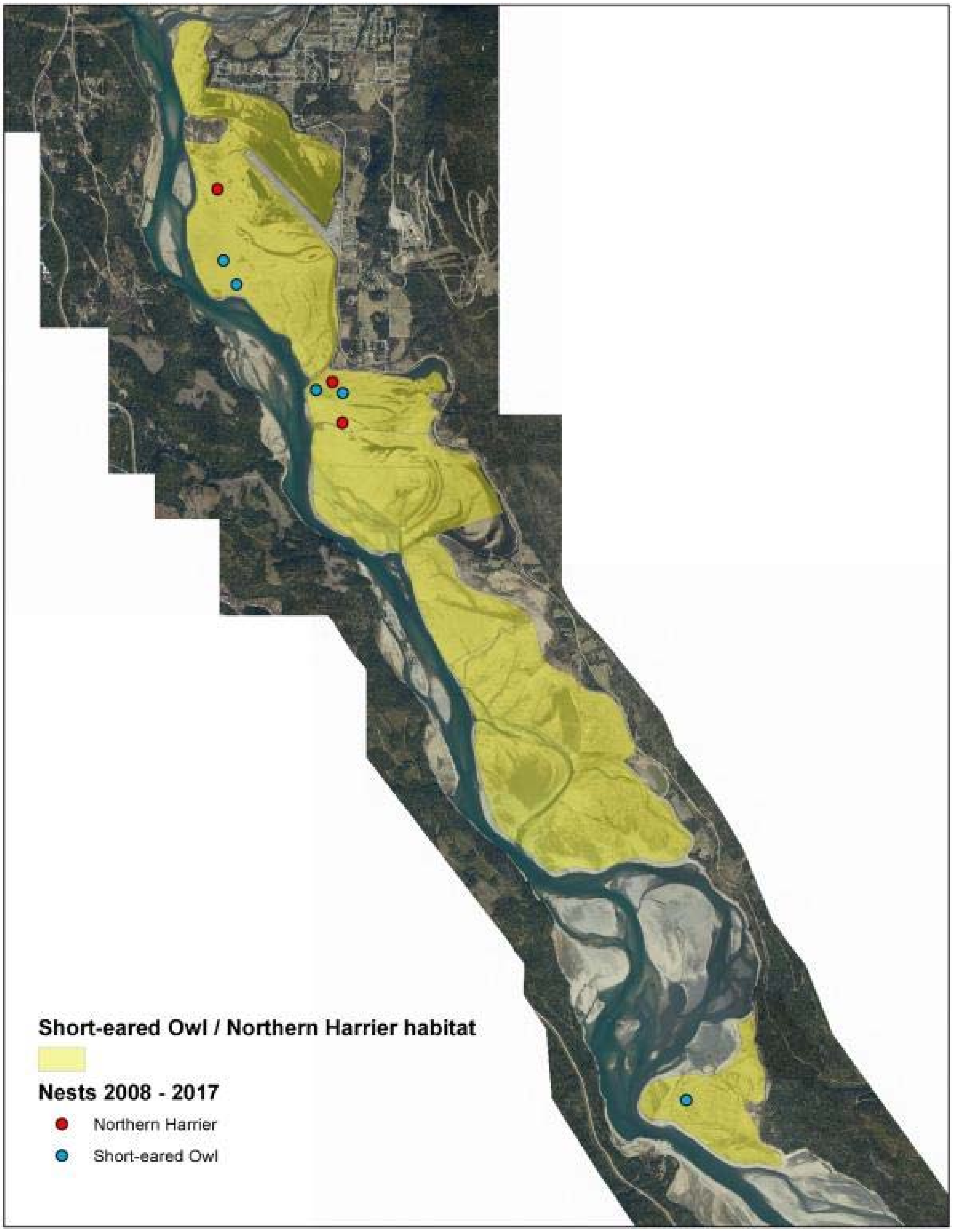
[9] Cooper Beauchesne and Associates. 2018. CLBMON-36: Kinbasket and Arrow Lakes Reservoirs: nest mortality of migratory birds due to reservoir operations— 10 Year Final Report, 2008-2017. BC Hydro Generation, Water Licence Requirements, Burnaby, B.C.

7.25 Birds detected during surveys for CLBMON-40. Not all are waterbirds, but the birds in this table are all affected by reservoir operations.

Common Name	Scientific Name
Pacific Loon	*Gavia pacifica*
Common Loon	*Gavia immer*
Pied-billed Grebe	*Podilymbus podiceps*
Horned Grebe	*Podiceps auritus*
Red-necked Grebe	*Podiceps grisegena*
Western Grebe	*Aechmophorus occidentalis*
American White Pelican	*Pelecanus erythrorhynchos*
Double-crested Cormorant	*Phalacrocorax auritus*
Great Blue Heron	*Ardea herodias*
Great Egret	*Ardea alba*
Cattle Egret	*Bubulcus ibis*
Green Heron	*Butorides virescens*
White-faced Ibis	*Plegadis chihi*
Trumpeter Swan	*Cygnus buccinator*
Tundra Swan	*Cygnus columbianus*
Greater White-fronted Goose	*Anser albifrons*
Snow Goose	*Chen caerulescens*
Cackling Goose	*Branta hutchinsii*
Canada Goose	*Branta canadensis*
Wood Duck	*Aix sponsa*
Gadwall	*Anas strepera*
Eurasian Wigeon	*Anas penelope*
American Wigeon	*Anas americana*
Mallard	*Anas platyrhynchos*
Blue-winged Teal	*Anas discors*
Cinnamon Teal	*Anas cyanoptera*
Northern Shoveler	*Anas clypeata*
Northern Pintail	*Anas acuta*
Green-winged Teal	*Anas crecca*
Eurasian Green-winged Teal	*Anas c. crecca*
Canvasback	*Aythya valisineria*
Redhead	*Aythya americana*
Ring-necked Duck	*Aythya collaris*
Greater Scaup	*Aythya marila*
Lesser Scaup	*Aythya affinis*
Surf Scoter	*Melanitta perspicillata*
White-winged Scoter	*Melanitta fusca*
Bufflehead	*Bucephala albeola*

Common Name	Scientific Name
Common Goldeneye	*Bucephala clangula*
Barrow's Goldeneye	*Bucephala islandica*
Hooded Merganser	*Lophodytes cucullatus*
Common Merganser	*Mergus merganser*
Red-breasted Merganser	*Mergus serrator*
Ruddy Duck	*Oxyura jamaicensis*
Osprey	*Pandion haliaetus*
Bald Eagle	*Haliaeetus leucocephalus*
Northern Harrier	*Circus cyaneus*
Merlin	*Falco columbarius*
Sora	*Porzana carolina*
American Coot	*Fulica americana*
Semipalmated Plover	*Charadrius semipalmatus*
Killdeer	*Charadrius vociferus*
Black-necked Stilt	*Himantopus mexicanus*
Spotted Sandpiper	*Actitis macularius*
Solitary Sandpiper	*Tringa solitaria*
Greater Yellowlegs	*Tringa melanoleuca*
Lesser Yellowlegs	*Tringa flavipes*
Sanderling	*Calidris alba*
Semipalmated Sandpiper	*Calidris pusilla*
Western Sandpiper	*Calidris mauri*
Least Sandpiper	*Calidris minutilla*
Baird's Sandpiper	*Calidris bairdii*
Pectoral Sandpiper	*Calidris melanotos*
Dunlin	*Calidris alpina*
Stilt Sandpiper	*Calidris himantopus*
Short-billed Dowitcher	*Limnodromus griseus*
Long-billed Dowitcher	*Limnodromus scolopaceus*
Wilson's Snipe	*Gallinago delicata*
Wilson's Phalarope	*Phalaropus tricolor*
Red-necked Phalarope	*Phalaropus lobatus*
Bonaparte's Gull	*Chroicocephalus philadelphia*
Mew Gull	*Larus canus*
Ring-billed Gull	*Larus delawarensis*
California Gull	*Larus californicus*
Herring Gull	*Larus argentatus*
Caspian Tern	*Hydroprogne caspia*
Black Tern	*Chlidonias niger*
Short-eared Owl	*Asio flammeus*
Belted Kingfisher	*Megaceryle alcyon*
American Dipper	*Cinclus mexicanus*

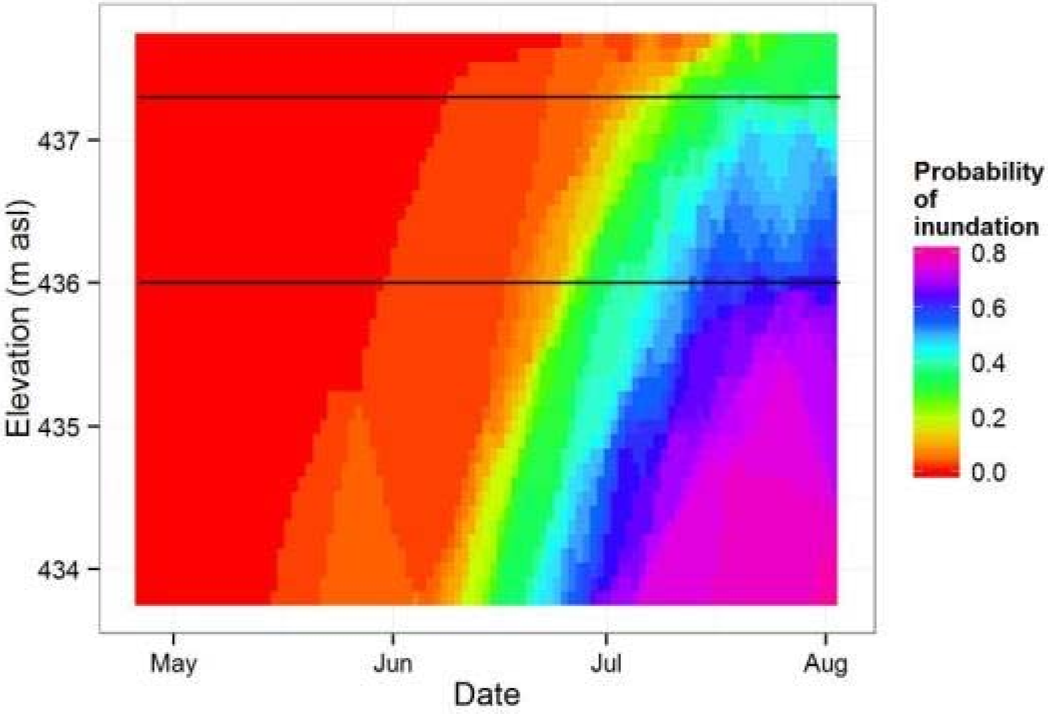
7.26 Northern Harrier and Short-eared Owl habitat and nests from 2008 to 2017.



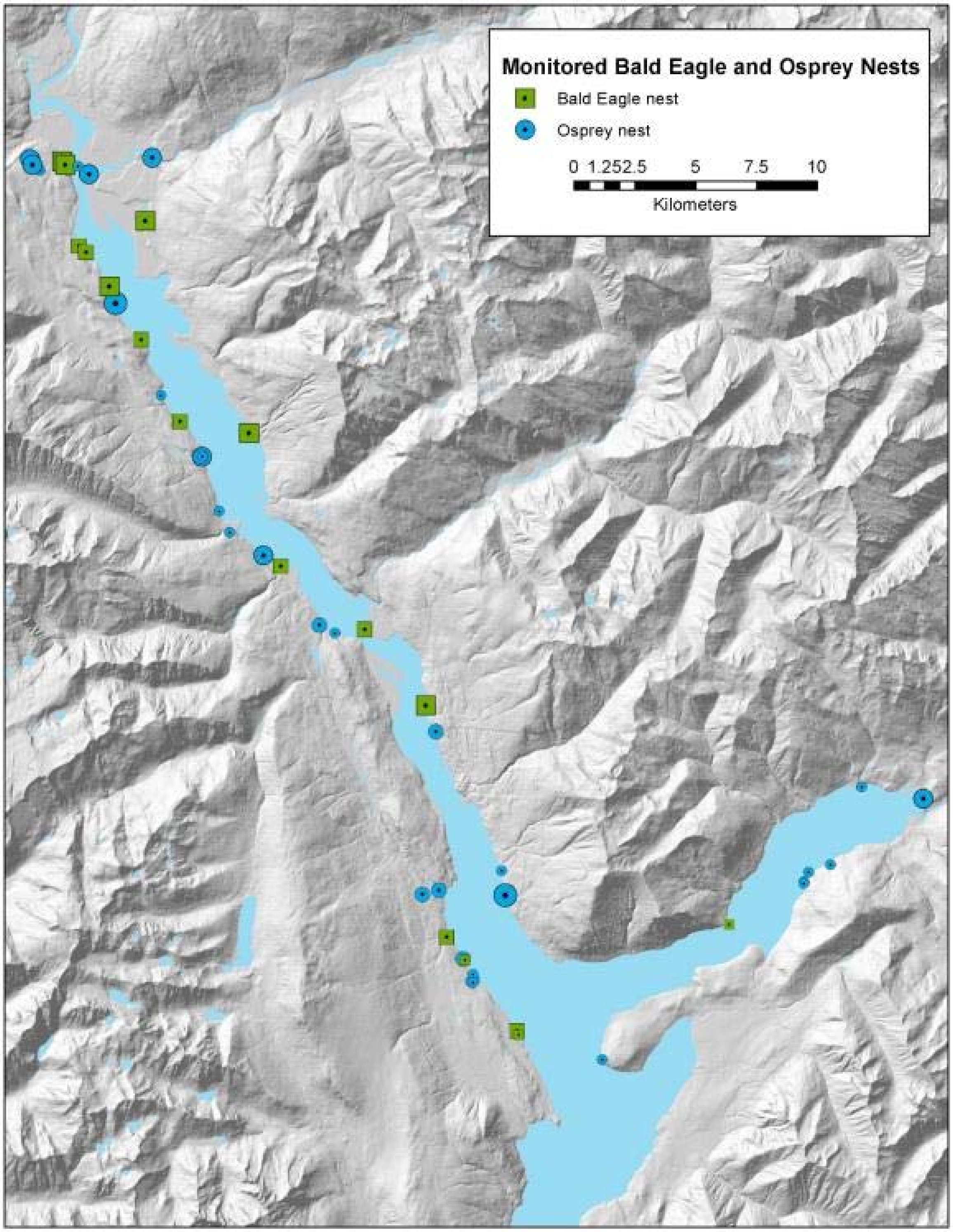
7.27 Summary of nest fates for Osprey during the course of CLBMON-40

Year	No. of nesting attempts	Successful Nests	No. of young fledged	Productivity	No. Young Produced from Successful Nests	Percent Successful Nests
2009	9	7	11	1.22	1.57	0.78
2010	12	6	10	0.83	1.67	0.5
2011	7	4	6	0.86	1.5	0.57
2012	8	2	2	0.25	1	0.25
2013	7	1	2	0.29	2	0.14
2014	10	4	9	0.9	2.25	0.4
2015	10	7	13	1.3	1.86	0.7
2016	9	2	3	0.33	1.5	0.22
2017	6	0	0	0	0	0

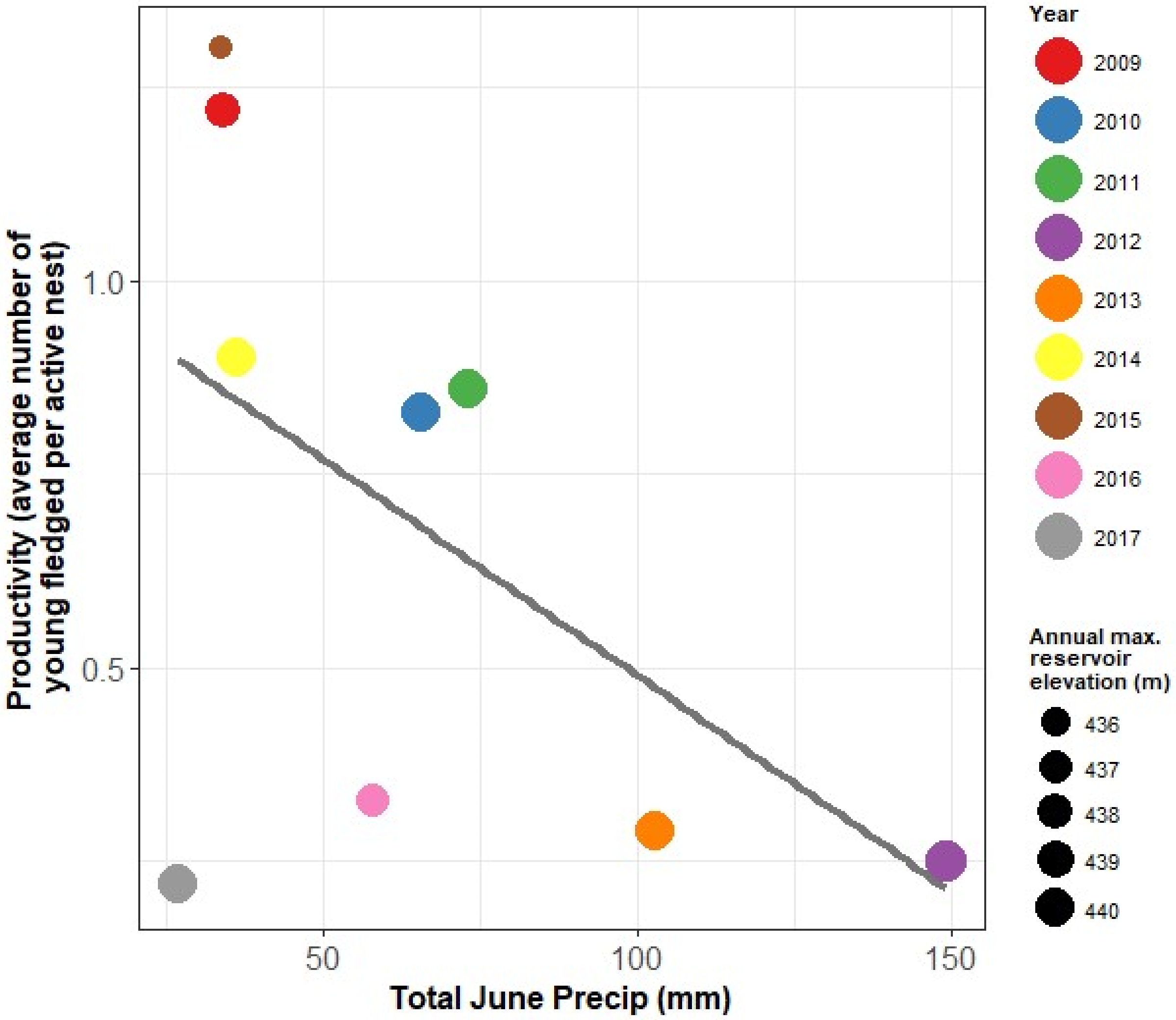
7.28 **A model of the probability of inundation of Short-eared Owl and Northern Harrier habitat based on historic reservoir operations. We estimate that for safe fledging of young, elevations at which nests occur must not flood prior to July 1. The two black lines bound the elevation band that Short-eared Owls were using for nesting.**



7.29 **Locations of Bald Eagle and Osprey nests in the study area. Symbol size represents the maximum number of young fledged from a nest. Smallest value is 0, largest is 3.**



7.30 Average number of Osprey young fledged per active nest.



7.31 Potential wildlife physical works projects

Location	Feature Description	Purpose
Downie Ponds	High elevation wetland	Create high elevation wetland at northern end of study area
Airport Marsh	Water control structure and berm at airport marsh	Control water level in Airport Marsh to protect the marsh from inundation
Airport West	Water control structure at airport west	Control water level in Airport West. Maintain a minimum water elevation. The berm at the south end is at risk of eroding and completely draining this wetland
Revelstoke Reach	Floating islands	Create floating islands to provide habitat when the reservoir is filling
Catherwood	Wetland enhancement at south end of Catherwood	Protect and improve a high elevation, linear wetland
12 Mile	Wetland construction at 12 Mile	Repair berm from Arrowhead rail line to create high elevation wetland

7.32 **Mapped locations of potential wildlife physical works projects. Floating islands described with a location of Revelstoke Reach are not mapped because they could be in multiple locations within the Reach.**

7.33 Timeline of CLBMON-40 activities

Year	Progress
2008	• First year of study. Field reconnaissance, site selection, and initial development of monitoring plan. • Spring land-based waterfowl surveys started late due to timing of contract initiation by BC Hydro. • Shorebird survey was a pilot study as that component could not be designed well due to incomplete understanding of shorebird habitat locations. • Waterfowl brood surveys were conducted as planned. • Monitoring of Bald Eagle and Osprey nests was conducted by land. • Surveys for Northern Harrier and Short-eared Owls were conducted. • Aerial survey budget was not yet available from BC Hydro.
2009	• Initiation of spring aerial surveys; surveys were not complete surveys, but always included high-use wetlands. • Initiation of shorebird survey following a study design developed after Year 1. All well-used sites were selected and monitored onwards.
2010	• First fall aerial surveys were conducted; these were the first complete surveys of Revelstoke Reach.
2011	• All aerial surveys were complete surveys from 2011 onwards.
2012	• No changes to monitoring program.
2013	• Changed data collection for Short-eared Owl and Northern Harrier to allow for roaming surveys of polygons, rather than point based surveys.
2014	• Land-based waterbird surveys stopped surveying channel habitat (9 mile, 12 mile) and focused on important wetlands.
2015	• Aerial surveys timed to fill in data gaps (reservoir and migration timing), helicopter used for all Bald Eagle and Osprey nest checks.
2016	• No changes to monitoring program.
2017	• No changes to monitoring program.