Evaluating the development and use of a rapid wetland assessment tool (ABWRET-A) in policy implementation in Alberta, Canada

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

While I am the sole author of this thesis, I must acknowledge that Dr. Rebecca Rooney helped me with editing my writing, and Dr. Derek Robinson provided me with GIS and inventory help, and solely analyzed and wrote up the methods for the spatial clustering analysis of the submission dataset. They will both be invited to be co-authors when publishing the manuscript of my data chapter.

Abstract

As wetlands around the world are being lost, policies are implemented to help protect further destruction and loss of valuable services that wetlands provide. In Alberta, wetland policy has been put in place with the goals of protecting the most valuable wetlands and replacing necessary loss of wetlands to maintain functional value. To help the policy meet its objectives, the Alberta Wetland Rapid Evaluation Tool-Actual (ABWRET-A) was developed and implemented in Alberta's settled area in 2015 as a standardized way to give a value score via functional assessment to any wetland in the province, with the hopes that the most valuable wetlands will be conserved. These assessment tools are in constant need of review and improvement to make sure they are helping meet policy goals.

I assess biases made in the selection for ABWRET-A calibration wetlands and determine how these biases affect ABWRET-A scoring to determine if subsequent scores provided by this tool are over or under estimating wetland value. I also assess the wetlands that underwent ABWRET-A evaluation and were drained or filled in under a permit in the 1.5 yr after ABWRET-A implementation in Alberta's settled region to determine whether they mirror the calibration wetlands.

I found that the calibration dataset comprised larger, more permanently ponded wetlands distributed closer to roads than the general wetland population. I also found that the calibration dataset included fewer bogs and more fens. I found that larger wetlands and wetlands classified as fens received higher ABWRET-A scores, whereas wetlands close to roads received lower scores. Consequently, I surmise that the scores being given out since ABWRET-A's implementation are likely underestimates. This is corroborated by a lower distribution of scores in the wetlands permitted for drainage than policy recommends. The wetlands being targeted for permitted loss were also smaller, more road-proximate, and concentrated around major cities, implying permanent regional loss of those wetlands and their functions.

Based on these findings, I make suggestions for improving ABWRET-A, including adding calibration sites to better capture the natural variability of wetlands in the area to improve ABWRET-A's accuracy in estimating relative wetland value.

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I thank my supervisor, Dr. Rebecca Rooney, for her constant guidance and support, and for pushing me when I needed it. You have an obvious passion for your students and want the very best for them, which is very commendable. Without you I wouldn’t have come close to finishing this thesis. I also thank my committee members, Dr. Derek Robinson and Dr. Roland Hall, who’s guidance and support helped me along. Special thanks to Dr. Derek Robinson, who’s help and expertise in GIS was crucial for the completion of this thesis.

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1 Literature Review

Wetlands are among the most valuable ecosystems in the world (de Groot et al., 2012). They are vital to the support of local biodiversity (e.g., Euliss and Mushet, 1999, Baschuk et al., 2012, Sulaiman et al., 2015), hydrological dynamics such as groundwater recharge and flood control (LaBaugh et al. 1998, Tiner 2003), global storage of excess carbon (Raghoebarsing et al., 2005), and can be sinks for excess nutrients (Crumpton and Goldsborough 1998). However, despite their indisputable value, about half of global wetland area has been lost since the 1800's (Zedler and Kercher 2005). Though the 1971 Ramsar Convention provides an international agreement whereby signing nations should protect the world's most significant wetlands, in many areas of the world state or provincial governments have a key role to play in wetland policy and management.

1.1 Wetland policy in Alberta, Canada

In Canada, wetland policy was introduced in 1991 with the Canadian Federal Policy on Wetland Conservation, where the Government of Canada committed to "no-net-loss" of wetland function (Government of Canada, 1991). However, wetland function was not well defined, and compensation for loss under a federal policy can only be requested if wetland loss is caused by a federally permitted or funded activity, resulting in the need for provinces to conceive provincial wetland policies to better protect against wetland loss (Lynch-Stewart, 1992).

Alberta's first wetland policy was introduced in 1993 and was deemed the "Interim Wetland Policy" (Alberta Water Resources Commission, 1993). Like the federal policy created two years earlier, the Interim Policy emphasized "no-net-loss" of wetland function. The idea was to reduce negative impacts to wetlands, and replace values or functions lost by these impacts by maintaining a given acreage of wetland stock. The policy had the objective to protect wetlands in only the settled area of Alberta (Figure 1.1), which is dominated by marsh and shallow open water wetlands. The Interim Wetland Policy was intended to slow down the rapid rate of wetland loss that had been happening in the most populated region of the province, while a province-wide and more comprehensive policy was developed (Alberta Water Resources Commission, 1993). Five-year reviews were intended to improve the policy as new knowledge was gained about wetland ecology and management. However, these policy reviews encountered difficulty obtaining support from environmental non-government organizations, industry groups, and the public. These setbacks delayed the expansion of the policy to all of Alberta for 20 years, during which time the policy goals were not met (Clare and Krogman, 2011). The Interim Wetland Policy has been criticized for providing little clarity or evidence of enforcement (Clare and Krogman, 2011, Clare and Creed 2014, Weber et al., 2017). For example, under the Interim Wetland Policy, wetland loss continued at a rate of 0.3-0.5% per year in the settled area, with wetland losses predicted to be much higher in the other parts of Alberta (Alberta Water Council, 2008) (Figure 1.1).

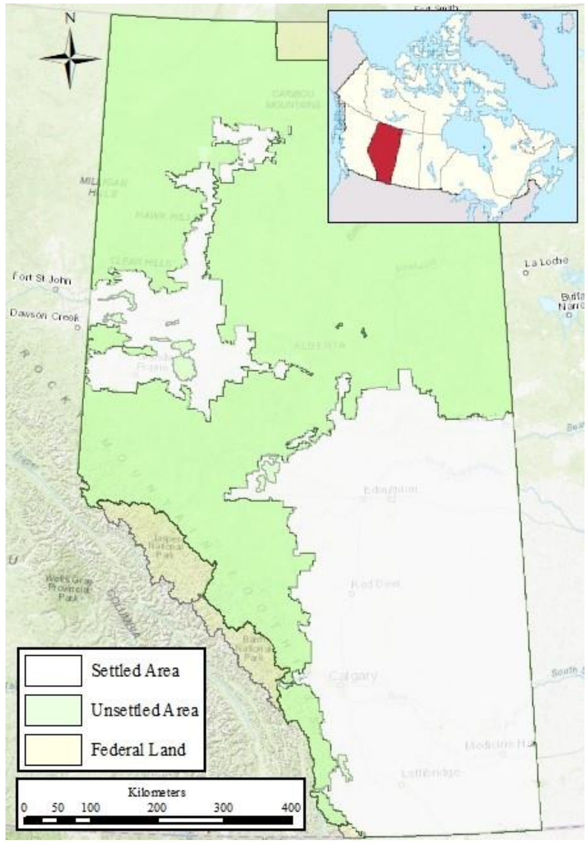

Figure 1.1: The province of Alberta, Canada divided into the settled area, unsettled area, and federal land, where provincial policies do not apply. The inset depicts Alberta in red in the context of the rest of Canada.

The new Alberta Wetland Policy, introduced in 2013, (hereafter "Alberta Wetland Policy") covers all of Alberta, not just the settled area. More, it has four explicit objectives that were more direct and hence easier to implement than the 1993 Interim Policy. The first objective is that the highest value wetlands in the province are protected. The idea being that though all wetlands provide value in some form, some wetlands provide greater value than others (e.g., Blackwell and Pilgrim, 2011). The second objective is that wetlands are conserved and restored in areas where wetland loss has been historically high, recognizing that historic loss has not been evenly distributed around the province (Creed et al. 2018). This will help minimize the cumulative effects of wetland loss over time by discouraging a disproportionately high concentration of wetland loss in particular areas. High concentrations of wetland loss can result in regional loss of ecosystem services provided by wetlands, which can be environmentally or economically degrading (e.g., Johnston, 1994, Weber et al., 2017). The third objective is that negative impacts to Alberta's wetlands are avoided, minimized, or, if wetland loss is necessary, wetland value is replaced. This helps the new Alberta Wetland Policy align with the "no-net-loss" goal of the federal wetland policy (Government of Canada, 1991). The fourth and final objective is that regional context is considered during wetland management. Regional context allows for things like wetland conservation areas if certain wetlands are deemed regionally important, or prioritization of areas for wetland restoration (Government of Alberta, 2013a). Regional context management also allows for slightly different implementation of the policy in the settled area where agriculture and urban areas dominate, compared with the boreal/foothills area of Alberta where logging and mining dominate (Downing and Pettapiece, 2006). Indeed, implementation of the Alberta Wetland Policy was staggered, coming into effect in the settled region in 2014 and the boreal/foothills region in 2016 (Government of Alberta, 2013a, Government of Alberta, 2016). These four clear policy objectives were made to help the 2013 Alberta Wetland Policy achieve greater success than its Interim predecessor, and, if the policy goals are met, would allow for successful conservation and efficient management of Alberta's wetlands, with emphasis on protecting the most valuable wetlands.

1.2 Wetland evaluation tools

Even with the best policy objectives, we cannot conserve or maximize a system's properties or processes until we are able to easily quantify them. As with the Alberta Wetland

Policy, which aims to protect the most valuable wetlands, wetland-specific management policies necessitate the development of assessment tools capable of rapidly evaluating wetlands to quantify their respective values. These tools help developers comply with wetland policies and, consequently, need validation and improvement. Rapid wetland evaluation in North America was first introduced in the 1970s (Reppert et al., 1979). In the intervening 50 years, many rapid wetland evaluation techniques have been developed, focusing mainly on two types: condition (i.e., integrity) assessments (e.g., Karr, 2016, Stoddard et al., 2006) and wetland functional assessments (e.g., Brinson, 1993, Smith et al., 1995).

The first type of assessment, ecological condition or integrity-based evaluations, encompasses chemical, physical, and biological integrity, and is defined by a wetland's ability to support a community similar in composition, diversity, and functional organization to that of undisturbed, natural reference sites in the same region (Karr and Dudley 1981, Karr et al. 1986). There are a few types of condition-based assessment tools that have been developed and tested on Alberta's wetlands. These include multi-metric indices (e.g., Bolding et al., 2020, Anderson, 2017), as well as a floristic quality assessment tool (Wilson et al. 2013). Condition-based assessment methods are effective at looking at cumulative effects on an ecosystem over time, and the ecosystem's ability to maintain ecological integrity (Stoddard et al., 2006). However, this method does not consider the relative value of each wetland based on different ecological functions that the wetland provides (Lemly and Gilligan, 2013).

If, rather than seeking to maintain wetlands in a natural state, we are hoping to preserve wetlands that maximize the provision of ecological functions, we need a tool that can estimate the relative level of wetland functions. Wetland functions can be defined as processes occurring within a wetland that provide value for that wetland, neighbouring ecosystems, and people

(Novitzki et al., 1997). Function-based wetland assessments are tools that estimate relative wetland value based on how well that wetland performs different important ecologically- or socially-valued functions relative to other wetlands in the area (Adamus, 1983). These functions can support wetland biology, such as providing habitat for animals and plants, or be non-biological, such as retaining and removing nutrients or storing floodwater (Government of Alberta, 2015).

When functions benefit people, we consider them wetland values (Whigham, 1997). For example, a marsh with very high stormwater storage capacity can be excellent in preventing floods, performing that function well. However, that wetland's capacity to store stormwater is not valuable if it is in an area with no people or human infrastructure. Conversely, a wetland with a small capacity to store stormwater might not perform that function as well, but could be more valuable if it is protecting real estate near a populated area. This weighting of functional performance based on human benefit helps us determine wetland value, an important aspect of function-based wetland assessment tools.

1.3 Alberta Wetland Rapid Evaluation Tool- Actual

The Alberta Wetland Rapid Evaluation Tool – Actual (ABWRET-A) is a function-based wetland assessment tool that was created in June 2015 to help the Alberta Wetland Policy meet its objectives. The Alberta Wetland Policy objective of protecting wetlands of the highest value is a difficult one to implement, as it requires a standardized way of determining relative wetland value. Under the Alberta Wetland Policy, relative wetland value is broadly interpreted to mean ecological and social importance and is premised on the notion that natural wetland functions result in the provision of ecosystem services that are of value to Albertans (Government of

Alberta, 2015). Therefore, to be successful in evaluating relative wetland value, ABWRET-A must measure wetland functions relative to other wetlands in the area. By characterizing the distribution of wetland function within each assessment area, the tool can then assign a score to each wetland that positions it relative to other wetlands in the region: the relative wetland value.

The ABWRET-A tool was built as a modified version of the Wetland Ecosystem Services Protocol for Southern Alberta (WESPAB) (Government of Alberta, 2013b). This ABWRET-A predecessor was built as a modification of the Wetland Ecosystem Services Protocol in the United States (WESP-US) (Adamus et al., 2010), which is applied with various modifications throughout North America (e.g., Adamus et al., 2009, Adamus, 2018). When the Government of Alberta was initially looking for a wetland assessment tool, WESP-US was considered as it was an existing tool that appeared to rapidly assess many functions that wetlands provide in the area (Government of Alberta, 2015). In 2013, WESP-US was tailored to the wetlands of southern Alberta and renamed WESPAB (Government of Alberta, 2013b). For example, reference to tidal marshes was removed, reference to geospatial data layers were altered, and units were converted to metric (Government of Alberta, 2013b).

When the Alberta Wetland Policy was published six months later and called for a wetland evaluation tool to evaluate the entire settled area of Alberta (Figure 1.1), Dr. Paul Adamus was contracted to develop ABWRET-A, expanding on WESPAB (Government of Alberta, 2015). Some modifications to WESPAB included the addition of the function stream flow support, as well as the conversion of an overall wetland rating system based on 14 wetland functions to a four-tiered value score (A, B, C, and D), as was required by the Alberta Wetland Policy. To better apply the assessment tool to the entire settled area of Alberta, and to more accurately score a wetland, ABWRET-A was further calibrated using 207 sample wetland sites in the northern settled area of Alberta to get an idea of the natural variability of functions from the area's wetlands (Government of Alberta, 2015). Following the 2015 release of an ABWRET-A tool suitable for application across the settled area of Alberta, a second version of ABWRET-A was released in July 2016 that expanded ABWRET-A to apply to the entire province, including the northern portion of the province (Government of Alberta, 2016).

The ABWRET-A assessment is a required component of any application for a permit to drain or fill a wetland anywhere in Alberta. The tool combines a scientific rationale for estimating the performance of 14 wetland functions (Table 1.1) with recommendations under the Alberta Wetland Policy for how to assign a wetland a score representing its perceived value (Figure 1.2). The policy requires equal weighting of four main wetland functions: biodiversity, water quality improvement, water quantity regulation (flood reduction), and human values (Figure 1.2). Further, the policy requires that measures of these four functions are averaged, then converted to a value score of either A, B, C, or D, where A represents wetlands with the highest value score, and D, the lowest. Furthermore, the value score is then be adjusted based on the extent of historic wetland loss where the wetland is situated, such that areas of high historic loss have their scores adjusted by increasing the value category by one letter grade (e.g., B becomes an A), and areas of low historic loss have their scores adjusted reducing their value category by one letter grade (e.g., B becomes a C). This adjustment is done to help protect wetlands situated areas of high historic wetland loss, one of the four main objectives of the new policy (Government of Alberta, 2013a). In doing this, ABWRET-A can provided a final value score of either A, B, C or D in a standardized manner to any wetland in Alberta.

Table 1.1: The 14 ABWRET-A functions and how they are associated with the four Alberta wetland policy functions. Function names and definitions were retrieved from the ABWRET-A Manual (Government of Alberta, 2015, page 6).

Policy Function	**ABWRET-A Function**	**Definition**
Biodiversity	Fish Habitat	The capacity to support an abundance and diversity of native fish (both resident and visiting species).
	Invertebrate Habitat	The capacity to support or contribute to an abundance or diversity of invertebrate animals which spend all or part of their life cycle underwater or in moist soil. Includes dragonflies, midges, clams, snails, water beetles, shrimp, aquatic worms, and others.
	Amphibian Habitat	The capacity to support or contribute to an abundance or diversity of native frogs, toads, and salamanders.
	Waterbird Habitat	The capacity to support or contribute to an abundance or diversity of waterbirds that nest or migrate through the region.
	Songbird, Raptor, & Mammal Habitat	The capacity to support or contribute to an abundance or diversity of native songbird, raptor, and mammal species and functional groups, especially those that are most dependent on wetlands or water.
	Native Plant & Pollinator Habitat	The capacity to support or contribute to a diversity of native, hydrophytic, vascular plant species, communities, and/or functional groups, as well as the pollinating insects linked to them.
Water Quality Improvement	Water Cooling	The effectiveness for maintaining or reducing temperature of downslope waters.
	Sediment Retention & Stabilization	The effectiveness for intercepting and filtering suspended inorganic sediments thus allowing their deposition, as well as reducing energy of waves and currents, resisting excessive erosion, and stabilizing underlying sediments or soil.
	Phosphorus Retention	The effectiveness for retaining phosphorus for long periods (>1 growing season).
	Nitrate Removal & Retention	The effectiveness for retaining particulate nitrate and converting soluble nitrate and ammonium to nitrogen gas while generating little or no nitrous oxide (a potent greenhouse gas).
	Organic Nutrient Export	The effectiveness for producing and subsequently exporting organic nutrients (mainly carbon), either particulate or dissolved.

Flood Reduction	Water Storage & Delay	The effectiveness for storing runoff or delaying the downslope movement of surface water for long or short periods.
	Stream Flow Support	The effectiveness for contributing water to streams during the driest part of a growing season.
Human Value	Human Value	Prior designation of the wetland as some type of officially protected area. Also, the potential and actual use of a wetland for low-intensity outdoor recreation, education, or research.

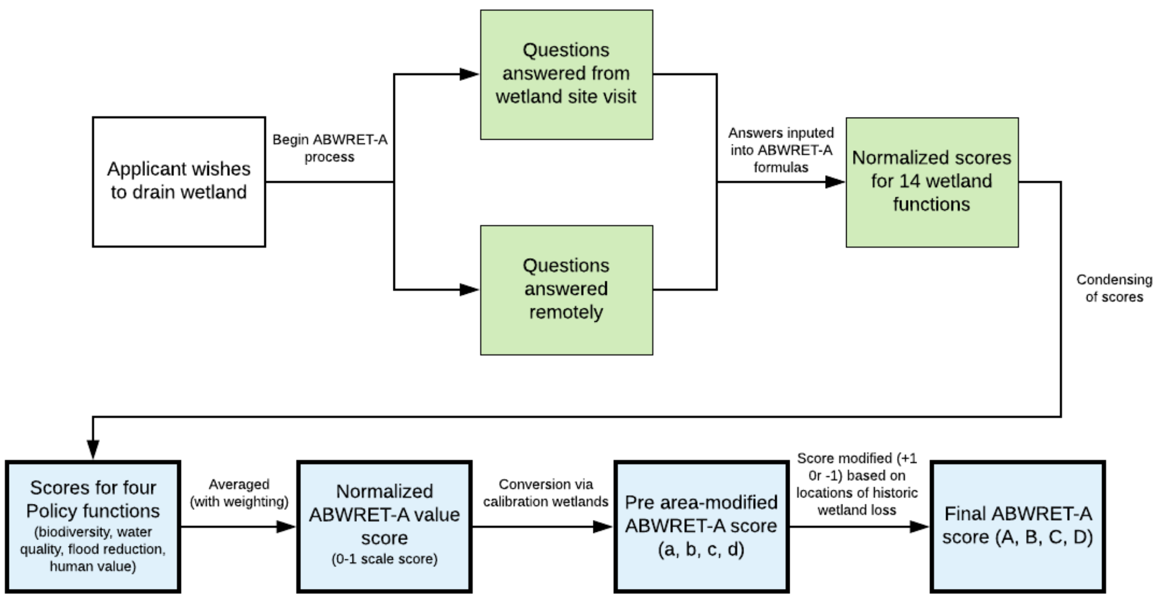

Figure 1.2: A visualization of the ABWRET-A scoring process. The top row of boxes represent the ABWRET-A scientific processes based on literature and other successful evaluation tools, and the bottom row of boxes are where the ABWRET-A process adjusts to align with provincial policy recommendations.

The final ABWRET-A score can determine acceptance of submitted application and, if accepted, the ratio of either wetland area to be replaced, or the size of the in lieu fee that must be paid (Figure 1.3, Table 1.2). Since studies have found that restored or created wetlands are lower in functional performance (e.g., Moreno-Mateos et al., 2012), it is always assumed that replaced wetland area will be of D-value (Government of Alberta, 2015).

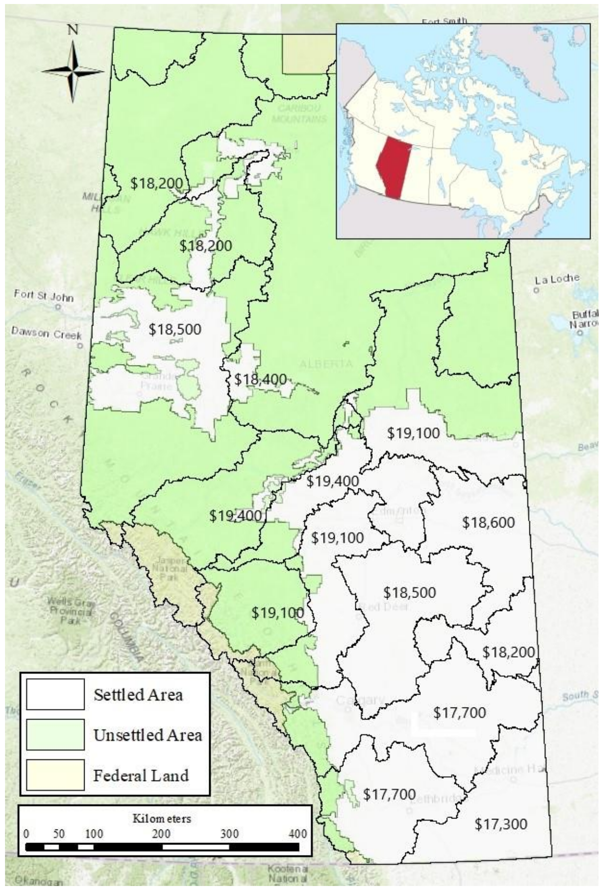

Figure 1.3: The province of Alberta, Canada, divided into relative wetland value assessment units (outlined polygons), which determine the cost of in lieu fee per hectare of drained wetland (labeled in each assessment unit) in combination with replacement ratios from Table 1.2. The labelled costs only apply if the wetland in question is situated in the settled area (white). If the wetland is situated in the unsettled area (green), the fee is automatically $10,300/ha. These values were retrieved from Government of Alberta (2018).

Table 1.2: Wetland replacement ratios for applicants wishing to drain a wetland according to the Alberta Wetland Mitigation Directive (Government of Alberta, 2018). These ratios apply both to the area of wetland in question as well as in-lieu fees (shown in Figure 1.3), always assuming (unless otherwise proven) that replaced wetlands will have a score of D. For example, if an applicant wanted to drain a C-value wetland, they would need to either replace it with two times the area (ratio of 2:1) or pay twice the in-lieu fee, which is about $18,000/ha depending on where the wetland is located (Figure 1.3) (Government of Alberta, 2018).

		Value of Replacement Wetland			
		D	C	B	A
Value of Lost Wetland	A	8:1	4:1	2:1	1:1
	B	4:1	2:1	1:1	0.5:1
	C	2:1	1:1	0.5:1	0.25:1
	D	1:1	0.5:1	0.25:1	0.125:1

Since its implementation in 2015, there has been no review of ABWRET-A. ABWRET-A is also the first wetland assessment tool to implement a function-based approach to wetland evaluation and assessment on the basis of relative value in terms of the four main functions: biodiversity, water quality improvement, water quantity regulation, and human values, and then weight that by historic loss rates. Since this technique is so novel, questions need to be asked about its effectiveness. Were any biases made in the calibration of ABWRET-A, where the natural variability of Alberta's wetlands were meant to be captured and used as reference for functional performance and scoring? How is ABWRET-A being used since its implementation? Over 2000 applications for drainage have been accepted over the course of a year and a half since ABWRET-A implementation, thus we need to ask: What types of wetland features are being targeted for permitted loss, and where is permitted loss occurring? If certain wetlands are being targeted for permitted drainage, can ABWRET-A be better calibrated to suit those wetlands so that it can more accurately score those wetlands? Is ABWRET-A helping the Alberta Wetland Policy meet its objectives? My thesis uses data on the 207 wetlands used to calibrate ABWRET-A in the settled area and the 2087 records of ABWRET-A evaluations submitted to the province as part of a wetland drainage permit application between January 2015 and June 2016 to address these questions to evaluate the early success of ABWRET-A in helping achieve the Alberta Wetland Policy's objectives.

2 Evaluating the development and use of a rapid wetland assessment tool (ABWRET-A) in policy implementation in Alberta, Canada

2.1 Introduction

2.1.1 The Alberta Wetland Rapid Evaluation Tool-Actual

Wetlands comprise a small percent of land cover but punch well above their weight-class in terms of ecosystem services provided (Zedler and Kercher, 2005). It has been argued that research into the ecosystem services provided by wetlands has led to a change in how we value all-natural assets (Maltby and Acerman, 2011). Recognition of the tremendous value of wetlands to society led to the establishment of national and provincial laws and regulations aimed at halting wetland loss (e.g., Austen and Hansen, 2006, Rubec and Hansen, 2008). Yet despite the broad adoption of no-net-loss policy goals (Sensu Maron et al., 2018), wetland functions or ecosystem services continue to decline (e.g., Hossler et al., 2011, Moreno-Mateos et al., 2015). The province of Alberta, Canada sought to turn the tide on the loss of wetland functions by adopting a new wetland policy in 2013 (Government of Alberta, 2013a), though implementation has faced several challenges (Weber et al., 2017). One important step toward implementation was development and calibration of a rapid assessment tool designed to quantify wetland function and provide a scoring system that enabled the ability of those making wetland permitting decisions to rank wetlands in terms of their provision of wetland functions. Wetland function can be defined as processes occurring within a wetland that provide value for that wetland, neighbouring ecosystems, and people (Novitzki et al., 1997). This function-based tool was called the Alberta Wetland Rapid Evaluation Tool – Actual (ABWRET-A) and was released for implementation in the southern portion of Alberta (i.e., the settled area) (Figure 2.1) in June 2015 (Government of Alberta, 2015).

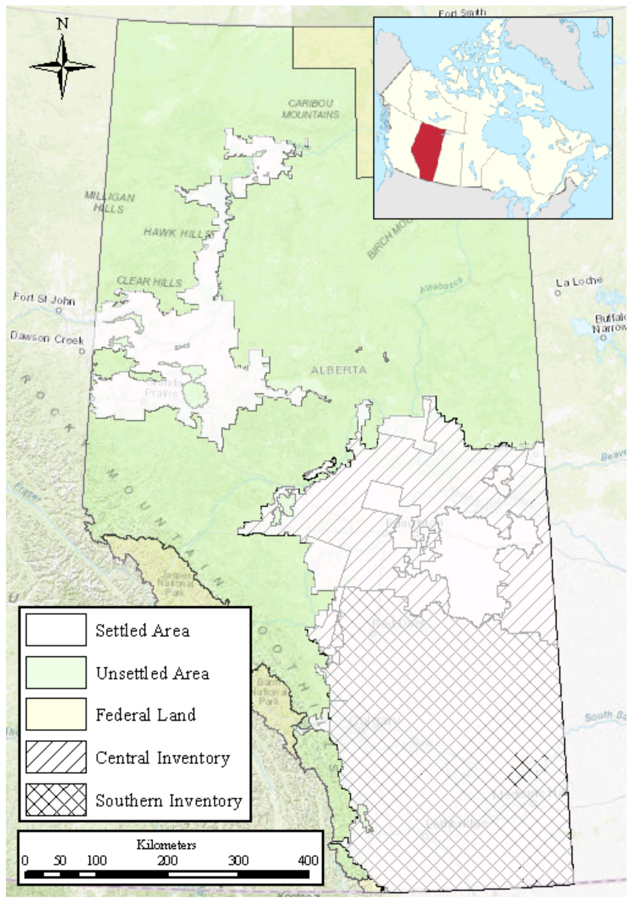

Figure 2.1: The province of Alberta, Canada, divided into the settled area, unsettled area, and federal land (where provincial policies do not apply). My focus for this paper will be ABWRET-A application in the settled area. Also shown here are the extents of the Central and Southern Alberta Wetland Inventories. The inset depicts Alberta in red in the context of the rest of Canada.

Function-based wetland assessments estimate a wetland's relative value based on how well that wetland performs different ecologically- or socially-valued functions relative to other wetlands in the area (Adamus, 1983). ABWRET-A adopts this function-based approach and assigns a relative value score based on estimates of 14 different wetland functions (Table 1.1). The 14 function scores are determined from both a checklist-style rapid assessment conducted by a Qualified Wetland Practitioner trained in implementation of the tool on-site, as well as off-site spatial analysis on connectivity and proximity to other features. The 14 function scores are then merged to give each wetland four policy-relevant scores: one for biodiversity support, one for water quality improvement, one for flood reduction and one for human value (Table 1.1). These four are integrated to yield a single continuous score ranging from 0-1, which is then binned into categorical grades A through D, such that A includes the top 10 percent of scores, B includes 70-89th percentiles, C includes 40-69th percentiles, and D includes wetlands scoring in the lower 40%. It was cited in the ABWRET-A manual (Government of Alberta, 2015) that these percentiles are dictated by the Government of Alberta. The conversion from continuous score to categorical grade is based on the distribution of wetland scores derived from a calibration process in which a set of 207 wetlands were evaluated to identify the natural distribution of possible scores. Lastly, if the wetland is situated in a management unit that has a high rate of historic wetland loss, then the grade is increased by one category, e.g., from a B to an A. Conversely, if the wetland is situated in a management unit with low historic wetland loss, then its grade is reduced by one category (Government of Alberta, 2015, See Figure 1.2 for the process of ABWRET-A scoring). Using this process, ABWRET-A can yield standardized, categorical ABWRET-A scores for each wetland in Alberta. Theoretically, these scores can enable landscape-level planning such that highly valued wetlands can be prioritized for conservation and mitigation and higher values can be ascribed in to wetlands in areas where the historic extent of wetlands has been reduced to encourage conservation and restoration in a regionally contextualized manner.

The final ABWRET-A score given to a wetland has many implications. It can determine the possibility of acceptance of a wetland drainage permit submission, or determine the replacement ratio of either 1) the area of wetland a developer must replace, or 2) the amount a developer must pay to replace the wetland they wish to remove (based on ratios from Table 1.2) (Government of Alberta, 2015). The Alberta Wetland Mitigation Directive (Government of Alberta, 2018) states that, since A-value wetlands are most valuable and least common, all applications for removing an A-value wetland must come with all possible alternatives to draining the A-value wetland, including at least one option that avoids removing the A-value value wetland entirely. If a wetland receives an ABWRET-A score other than A, and the permit to remove the wetland is accepted, the applicant must either replace that area of wetland lost with the appropriate area based on a replacement ratio dictated by the score of the wetland restored or created to replace it (Table 1.2), or pay an in-lieu fee that assumes the replacement wetland area will score a D (Government of Alberta, 2015).

2.1.2 ABWRET-A Calibration

A critical step in adapting the ABWRET-A tool to the Alberta Wetland Policy implementation needs was to calibrate the tool to the region. The continuous ABWRET-A scores (0-1) were converted to a grade (A to D) based on the distribution of scores among the set of 207 calibration wetlands, which were assumed to represent the natural distribution of wetland functions within the region (Government of Alberta, 2015). For an evaluation tool to be accurate, it must be calibrated correctly (Innis et al., 2000, Seegert, 2001, Stein et al., 2009, Gustavson and Kennedy, 2010). For ABWRET-A, which aims to estimate the performance of functions provided by a wetland relative to other wetlands within the surrounding area, this includes choosing calibration sites that accurately represent the natural variability of wetlands in the area of application. If the calibration sites are not representative of the natural variability of wetlands in the area of tool application, ABWRET-A could be biased and either over or underestimate the relative functions of a wetland being scored.

The ABWRET-A calibration wetlands were chosen via a non-random, systematic sampling method (Government of Alberta, 2015). Generally, calibration wetland selection was based on geospatial data layers like soil type, which yielded "clusters" of similar wetlands to ensure representation in the calibration sample frame. However, the documentation on the calibration process reveals some aspects of site selection that could introduce bias in the ABWRET-A calibration process such as only sampling the northern part of the settled area, and a preference for more permanently-ponded wetlands (Government of Alberta, 2015). To ensure an unbiased calibration so that application of the tool would be comparing wetlands to a baseline level of wetland function representative of the area of application, the calibration wetlands should have mirrored the frequency distribution of 1) wetland size, 2) distance from roads 3) wetland type, and 4) wetland permanence class that is present in the natural population of wetlands in area. Otherwise, the tool risks misrepresenting the relative value of a wetland within its landscape.

Although small wetlands are recognized as important in landscape function (Cohen et al. 2016), biogeochemical cycling (Marton et al. 2015), hydrologic processes (Rains et al. 2016), and their contribution to biodiversity (Semlitsch and Bodie 1998), large wetlands may provide greater function levels or different functions entirely (Mensing et al., 1998, Acreman and Holden, 2013, Evenson et al., 2018). If the calibration wetlands are larger on average than is typical for the area of ABWRET-A application, this might set the baseline for wetland function too high, resulting in a lower score being assigned to wetlands targeted for drainage than is warranted based on the conversion bins set by the calibration wetlands. In other words, fewer wetlands would receive an A score than the desired top 10% and more would receive a D than the desired lowest 40%.

The calibration documentation also indicated that site selection favored wetlands that were only a short distance (<300 m) from the nearest road (Government of Alberta, 2015). This access bias is common in monitoring and research programs due to the logistical and budgetary constraints around accessing remote sites, yet the roads may also act as a source of disturbance and stress on nearby wetlands. Wetlands situated near roads are often identified as having impaired function (e.g., Findlay and Bourdages, 2000, Miller and Wardrop, 2006, Shulse et al, 2010, Johnson et al., 2013). If calibration wetlands are situated closer to roads than the wetlands typically found in the area of ABWRET-A application, this could therefore set the baseline for wetland function lower than it should be. Consequently, the value of wetlands surveyed with the tool could be overestimated.

Further, I know that wetland functions differ by wetland type and that there can be trade-offs among ecosystem services (Bennett et al., 2009). A bog may be excellent at sequestering carbon (e.g., Raghoebarsing et al., 2005), but it is not likely to provide sustainable water quality improvement if it is loaded with agricultural runoff (e.g., Gustafson and Wang, 2002, Zedler, 2003). Conversely, a marsh may better support waterfowl and songbird abundance and diversity (Baschuk et al., 2012, Sulaiman et al., 2015) but could be a net source of greenhouse gases (e.g., Sha et al., 2011). Thus, for the baseline set by the calibration wetlands to accurately reflect the level of service typical of wetlands in an assessment area, the calibration dataset needs to reflect the frequency distribution of wetland types in that area. Yet, it was described that the calibration sites were located in the northern part of the settled area (Government of Alberta, 2015), and since there is a disproportionately high abundance of swamps and fens in the northern part of the settled area, and low abundance of marshes (Figure 2.2), the proportion of wetland types could differ between the calibration wetlands and the natural population of wetlands in the area of study. This would likely add to the misrepresentation of scores, particularly if certain wetland types consistently score more highly than others.

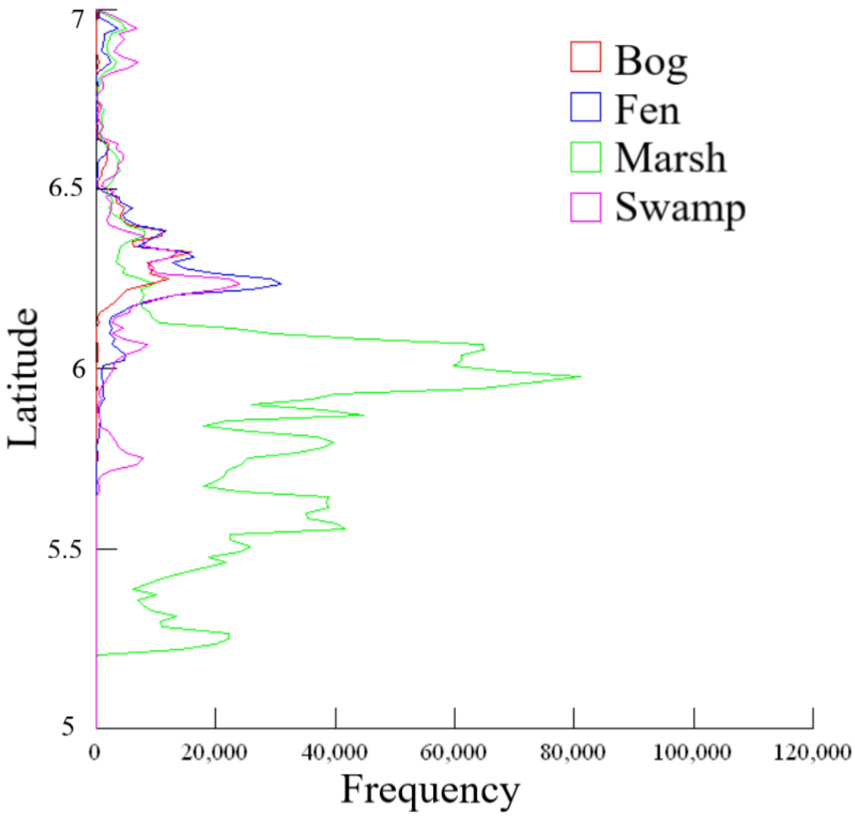

Figure 2.2: The frequency of wetland types in the Alberta Merged Wetland Inventory as defined by the Canadian Wetland Classification System (National Wetlands Working Group, 1997) at varying latitudes. Marshes and shallow open water wetlands were combined into the "marshes" category to stay consistent with the Alberta Wetland Classification system (ESRD, 2015), which is used by ABWRET-A. Latitudinal coordinates are x 1,000,000 and are in the Alberta 10-TM coordinate system.

Finally, wetland permanence class is typically correlated with its size (Babbitt, 2005). If the ABWRET-A calibration wetlands are larger than average for the area, this might imply they are more permanently ponded, too. More, the details on ABWRET-A calibration note that ephemeral marshes were avoided (Government of Alberta, 2015), suggesting that larger and more permanently ponded marshes may have been favored in calibration site selection. If the proportion of permanence classes differs between the calibration wetlands and the natural population of wetlands in the settled area of Alberta, and ABWRET-A scoring favours more permanently ponded wetlands, this would lead to undervaluing temporarily ponded or ephemeral wetlands, despite recent research indicating that these are ecologically important (e.g., Cohen et al. 2016, Marton et al. 2015, Rains et al. 2016).

2.1.3 ABWRET-A's Use Since Implementation

It is also illuminating to consider whether the wetlands being targeted for permitted loss comprise a representative subsample of all the wetlands in the applied area, or whether there is a certain size, distance to nearest road, geographic location, type, or permanence class that is favoured by developers and consequently subject to greater rates of wetland loss. Historically, smaller wetlands have been targets for drainage in Alberta (Van Meter and Basu, 2015, Serran and Creed, 2016, Serran et al., 2018), and wetland drainage is often concentrated around urban and suburban areas (Hasse and Lathrop, 2003, Gutzwiller and Flather, 2011, He et al., 2014, Mondal et al., 2017). Further, road density is often a proxy for human development, and wetlands located near roads are more likely to be developed than wetlands further away from roads (Gutzwiller and Flather, 2011). This leads to the possibility that the wetlands targeted for permitted loss since ABWRET-A's implementation are not a random sub-sample of all the wetlands in the area, but rather could be smaller, and more clustered around cities and roads. If certain wetland features such as size, distance to roads, geographic area, type, or permanence class are being preferentially lost over others, this will change the distribution of wetland properties in the landscape and affect how wetland ecosystem services are provided at a regional level.

In order to observe any potential effect of calibration biases on ABWRET-A scoring, I can use the distribution of ABWRET-A scores from the tool's use since implementation to see if the tool is giving out fewer As and more Ds (or vice versa) than the ABWRET-A manual recommends. This can help me determine if the calibration biases are, in fact, causing incorrect scores to be calculated for wetlands submitted for drainage since ABWRET-A's implementation.

I aim to determine whether the calibration of the ABWRET-A tool accurately reflects the type of wetlands present across the region of its application and the wetlands that are being targeted for development under the new wetland policy. I will test for A) biases in certain wetland features in the calibration wetlands such as wetland size, distance to the nearest road, type, and permanence class against both the natural population of wetlands in the settled area of Alberta, and the sites targeted for permitted loss since ABWRET-A's implementation, and B) how any biases affect ABWRET-A scoring. Further, I aim to assess whether the wetland policy objectives are likely to be achieved through application of the ABWRET-A tool. Thus, I will test for C) differences in the distribution of ABWRET-A scores between ABWRET-A recommendations and wetlands that have underwent permitted loss since ABWRET-A implementation, and D) biases in features such as size, distance from roads, geographic location, type, and permanence class of sites being targeted for permitted loss since ABWRET-A's implementation against the natural population of wetlands in the settled are of Alberta.

2.2 Methods

2.2.1 General approach

First, I will determine the representativeness of distributions of calibration wetland properties such as size, distance to the nearest road, type, and permanence class compared to the distributions of both the natural populations of wetlands in the study area, and the sites being targeted for permitted loss since ABWRET-A's implementation. This will tell me if ABWRET-A can be better calibrated to represent both the natural population of wetlands, and the wetlands that are being targeted for permitted loss.

Second, I will test to see A) the magnitude to which those wetland features (size, distance to the nearest road, type, and permanence class) influence normalized ABWRET-A value score and B) the direction in which those features affect normalized ABWRET-A value score. This will tell me if biases in the ABWRET-A calibration site selection process are affecting how ABWRET-A scores wetlands that are undergoing permitted loss using ABWRET-A under the Wetland Mitigation Directive (Government of Alberta, 2018).

Next, I will compare the distributions of ABWRET-A scores between the ABWRET-A manual recommendations (Government of Alberta, 2015), the calibration wetlands, and the wetlands that underwent permitted loss in the first year and a half following ABWRET-A implementation. A difference in ABWRET-A score distribution could confirm the possibility that scores coming from ABWRET-A's use since implementation are affected by biases made in ABWRET-A calibration, and that incorrect scores are coming from ABWRET-A's use.

Finally, I will compare the distributions of wetland features such as size, distance to the nearest road, geographic location, type, and permanence class of wetlands targeted for permitted loss under the Wetland Mitigation Directive (Government of Alberta, 2018) compared to the natural variability of wetlands in the study area to test the null hypothesis that the wetlands permitted for loss are a random selection of wetlands from the inventory of wetlands in Alberta's settled area. If certain wetland features are being preferentially drained over others, this implies a regional loss of ecosystem services and could have implications for strategic wetland management.

2.2.2 ABWRET-A Scoring

Two versions of the ABWRET-A tool have been developed: the first version was released in June 2015 and applies to the settled area of Alberta (Figure 2.1) where the dominant human land uses are urban and agriculture (Government of Alberta, 2015). The second version of ABWRET-A, released in July 2016, applies to the unsettled area where forestry and oil and gas activities dominate (Government of Alberta, 2016). This second version is not considered in this study because there were not enough sites (six outside of the settled area) evaluated with ABWRET-A at the time of analysis. Consequently, herein ABWRET-A refers to the tool used in the settled area of Alberta (Figure 2.1).

2.2.3 Datasets

My analyses rely on comparisons among four primary datasets: the calibration dataset that is instrumental in how wetlands are graded; the submission dataset that includes all the ABWRET-A applications submitted for scoring between January 2016 and June 2017; the wetland inventory, that includes basic information (size, type, location) on all the wetlands mapped within the settled area of Alberta; and the central and southern Alberta inventories, which contain permanence class information on mapped wetlands for most of the settled area (Figure 2.1).

The Calibration Dataset

The calibration dataset includes 207 wetlands from the settled area of Alberta (Figure 2.1) that were sampled in 2014 by Dr. Paul Adamus and his calibration team. Each calibration wetland underwent the ABWRET-A evaluation process and contains all the corresponding ABWRET-A data, but I was not able to obtain their specific geographic coordinates. The calibration wetlands are used to standardize function scores in different areas of the settled area, as well as set bins to convert normalized ABWRET-A value scores (0-1 scale scores) into a letter grade (A, B, C, or D).

The Submission Dataset

The submission dataset included 2093 applications for wetland removal between January 1st, 2016 and June 15th, 2017, but was cut down to 2087 wetlands as a few sites were found outside the settled area of Alberta. Each wetland in the submission dataset was evaluated by a trained Qualified Wetland Science Practitioner who applied ABWRET-A to wetlands on behalf of developers seeking permits to drain or fill wetlands. The resulting dataset contains all of the corresponding ABWRET-A data as well as the coordinates of each wetland's geographic location. This dataset represents the wetlands that are being targeted for permitted wetland loss in Alberta's settled area in the year and a half immediately following ABWRET-A implementation.

The Alberta Merged Wetland Inventory

The best approximation of the true population of wetlands in the province comes from the provincial wetland inventory. The Alberta Merged Wetland Inventory (the inventory, herein) is a compilation of 35 remotely-sensed sources of data collected between the years of 1998-2015 and covers all of Alberta except for federal land (See Figure 2.1 for federal/provincial land differentiation in Alberta) (Alberta Environment and Parks, 2018). This inventory was evaluated by Hird et al. (2017) and found to have 85% "probability-of-occurrence" accuracy (see Figure 2.3 for error types in the inventory). The inventory contains basic information including wetland type as characterized into bog, fen, swamp, marsh, and shallow open water under the Canadian Wetland Classification System (National Wetlands Working Group, 1997). For the sake of comparison, wetlands classified as either "marsh" or "shallow open water" were grouped into the "marsh" category, as ABWRET-A uses the Alberta Wetland Classification system (ESRD, 2015), that does not differentiate between marsh and shallow open water wetlands. The inventory also reports on wetland size and perimeter (Alberta Environment and Parks, 2018). The dataset was provided in the form of a feature class dataset and contains a total of 1,782,001 wetlands in the settled area of Alberta.

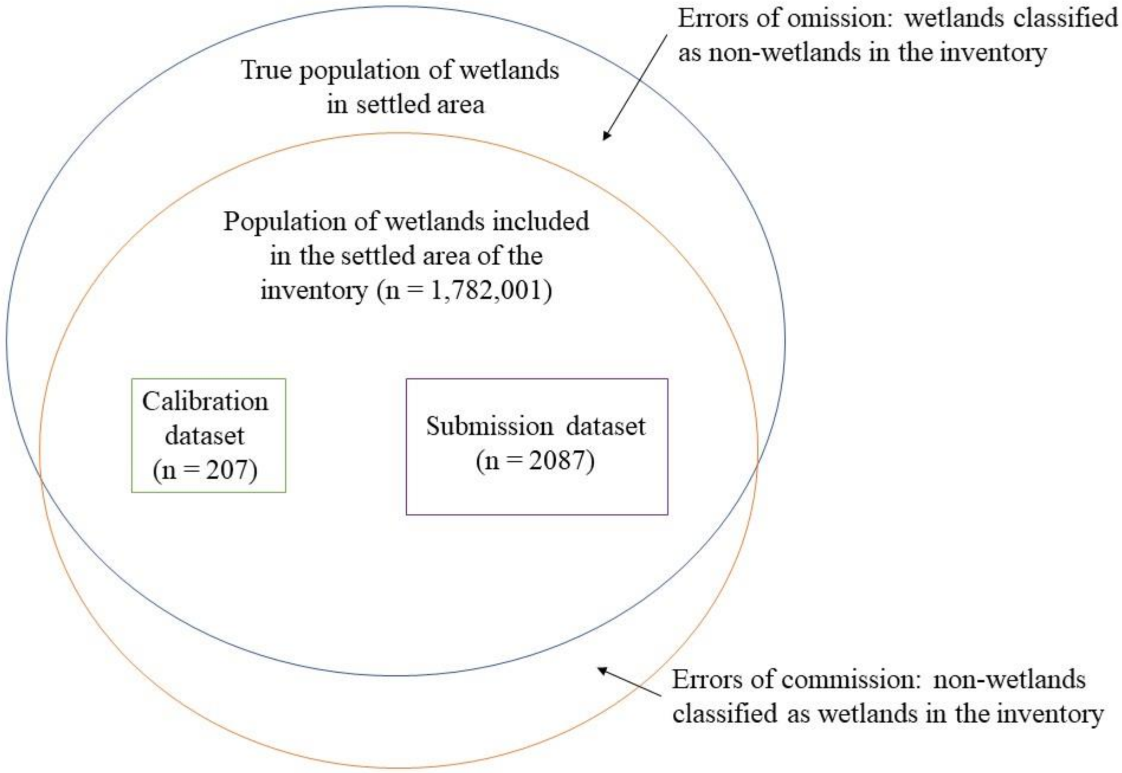

Figure 2.3: A visual representation of the sources of error in the Alberta Merged Wetland Inventory (the inventory). Also included are the calibration and submission datasets for reference of how they are subsets of the true population of wetlands in the settled area of Alberta.

<u>The Central and Southern Alberta Wetland Inventories</u>

Unfortunately, the inventory does not include information about wetland permanence class, so to address this research question, I will use the Central and Southern Alberta inventories, which span most of the settled area of the province (Figure 2.1) and divide all wetlands into one of five permanence class bins: temporary, seasonal, semi-permanent, permanent, or alkali following nomenclature by ASRD (2010a). However, the ABWRET-A data in the calibration and submission datasets only included permanence class data on marshes, so for comparison's sake, only marshes were included in permanence class comparison between the ABWRET-A datasets (calibration and submission) and the central and southern Alberta inventories. The southern inventory only consisted of marshes, but the central inventory differentiated wetland type by percent breakdown via the Canadian Wetland Classification System (National Wetlands Working Group, 1997). So, for comparison, all wetlands that had a sum of marsh + shallow open water less than 50% were removed from analysis. The resulting combined central and southern Alberta inventories contained 568,248 marsh-classified wetlands in the form of a feature class dataset and contained data such as wetland size, perimeter, location, and permanence class.

An accuracy assessment of the central inventory found an 82.6% accuracy in correctly measuring wetland permanence class (ASRD, 2010b) and an accuracy assessment of the Southern inventory found the accuracy of determining wetland permanence class ranged from 51% to 68% (Alberta Terrestrial Imaging Center, 2009).

2.2.4 Permanence Class

The calibration and submission datasets report wetland permanence class of marsh wetlands as either "temporary-seasonal" or "seasonal-permanent", and so to compare the permanence class of wetlands in the central and southern inventories with the permanence class of wetlands in the calibration and submission datasets, I had to combine temporary and seasonal permanence classes into a single bin and semi-permanent and permanent classes into a second bin. I excluded wetlands from the central and southern inventories that were assigned a class of alkali, as these were not represented in the calibration and submission datasets. The excluded alkali wetlands accounted for 6,920 wetlands, or 1.1% of total cases.

2.2.5 Proximity to Roads

I determined the distance from each wetland to the nearest road for all the wetlands in submission and inventory datasets. The distance between the wetland edge and nearest road was included in the calibration dataset and so I did not calculate it. Unfortunately, only wetland centroid locations were provided for the submission dataset, and so I calculated road distances from the wetland centroid.

To test whether this difference in measure would influence the outcome of my analyses, I measured the distance to nearest road for each wetland in the inventory dataset from both the centroid and the edge, using the “near” feature in the “proximity” toolset via ArcMap, v. 10.4.1 (ESRI, 2016). This tool calculated nearest straight-line distance between either the wetland edge or the wetland centroid. The difference in road distance medians measured between wetland centroids (449.5 m, interquartile range = 685.8) versus edges (399.7 m, interquartile range = 684.8) was 49.8 m. Because this difference in median values is an order of magnitude less than the median distance to nearest road calculated by either method, I concluded that the difference was inconsequential for my purposes. I used the distance from the wetland edge to the nearest road in all subsequent analyses of the inventory dataset.

2.2.6 Analyses

I evaluated whether A) there were biases made in the selection of wetlands used to calibrate ABWRET-A, B) if ABWRET-A is suitably calibrated for wetland features being targeted for permitted loss, and C) if there were certain wetland features that were being targeted by developers applying for wetland drainage permits. In particular, I tested whether there were differences in the distributions of wetland sizes, proximity to roads, types, or permanence class among the three datasets, and if the wetlands targeted for permitted loss were randomly distributed in the settled area of Alberta, or if they were concentrated in certain areas. For any features (sizes, road distances, types, or permanent classes) that differed significantly among datasets, I tested to see the effect that each feature had on normalized ABWRET-A value scores. This elucidated whether the difference between datasets would result in an over or underestimate of wetland function by the ABWRET-A tool. I did this by calculating whether the proportion of ABWRET-A scores (A, B, C, or D) differed between the wetlands in the submission dataset, the calibration dataset, and the ABWRET-A manual recommendation for distribution of scores to see if biases made in ABWRET-A calibration are affecting scores coming from ABWRET-A's use since implementation in the submission dataset.

For the two continuous variables of wetland size and distance to the nearest road I used boxplots to visually compare the distributions among my three datasets of interest. I then used a Kruskal-Wallis test to establish whether a statistically significant difference in the distribution of wetland features existed among the three datasets (Kruskal and Wallis, 1952). I then carried out post-hoc pair-wise comparison testing of the size and distance to nearest road distributions using a Dwass-Steel-Critchlow-Fligner test, which controls for family-wise error rate (Critchlow and Fligner, 1991). These non-parametric tests were appropriate because these wetland properties were non-normal in distribution, confirmed by Shapiro-Wilk tests (Shapiro and Wilk, 1965).

To determine the effect of wetland size and distance to the nearest road on normalized ABWRET-A value score, I used scatterplots to visually compare trends. I combined the calibration and submission datasets into a single dataset for these analyses since they both contain the data in question, and were gathered the same way through ABWRET-A. I then performed linear regressions to determine significance of the trend.

Next, to determine any spatial clustering of the submission wetlands, a cluster analysis was conducted using the Getis-Ord G_i^* statistic (Getis and Ord, 1992). The G_i^* statistic was applied to a series of grids covering the settled area of Alberta (Figure 2.1) comprising cell resolutions of 6, 12.5, 25, and 50 km to ensure robust results against the modifiable areal unit problem (Openshaw, 1981). Grid-cell values represented the number of wetland centroids residing within the cell, which were tested against a Poisson distribution using the Chi-squared statistic.

For the two categorical variables of wetland type and permanence class, I used stacked bar charts to visually compare proportions among datasets. I then used a G-test goodness of fit contingency table (McDonald, 2014) to determine whether the distribution of types and permanence classes in the wetland inventories was mirrored in the calibration and submission datasets. If significant, this was followed by multiple pair-wise G-tests for each variable versus the sum of the other variables (types or permanence classes in the calibration dataset versus the inventories, or the submission dataset versus the inventories), with a Bonferroni correction to test significance (Bonferroni, 1936).

To determine the effect of wetland type and permanence class on normalized ABWRET-A value score, I used boxplots to visually compare the distributions of normalized ABWRET-A value scores at each categorical variable. I then used a Kruskal-Wallis test (Kruskal and Wallis, 1952) to establish whether a statistically significant difference in the distribution of normalized ABWRET-A value scores existed among wetland types. If significant, I then carried out post-hoc pair-wise comparison testing of the types and permanence classes using a Dwass-Steel-Critchlow-Fligner test (Critchlow and Fligner, 1991). I also used a Mann-Whitney test (Mann and Whitney, 1947) to see if normalized ABWRET-A value scores differed significantly between permanence class ranges (temporary-seasonal and seasonal-permanent). These were appropriate because these wetland properties were non-normal in distribution, confirmed by Shapiro-Wilk tests (Shapiro and Wilk, 1965).

Finally, I evaluated whether the distribution of pre-modified ABWRET-A scores (A, B, C, or D) before the modifier for area of historic wetland loss (Figure 1.2) obtained in the submission and calibration datasets conforms to the expected distribution, dictated by the Government of Alberta in the ABWRET-A manual (Government of Alberta, 2015), whereby the top 10% of scoring wetlands should be an A, the following 20% B, the following 30% C, and bottom 40% should be a D. I used a G-test goodness of fit contingency table (McDonald, 2014) to see if the distributions of ABWRET-A scores differed significantly between both the submission sites and the recommendation, and the calibration sites and the recommendation. If significant, this was followed by multiple pairwise G-tests for each ABWRET-A score versus the sum of the other ABWRET-A scores, with a Bonferroni correction α to test significance (Bonferroni, 1936). I tested for categorical ABWRET-A scores (as opposed to the normalized ABWRET-A value scores that I tested in the comparisons of sizes, road distances, types, and permanence classes) to see if the distribution of scoring bins set by calibration wetlands do result in the desired distribution of scores among submission wetlands or whether the submission wetlands have disproportionally lower scores (i.e., more Ds, fewer As) than specified in the ABWRET-A manual (Government of Alberta, 2015).

2.3 Results

2.3.1 Size

Wetland sizes differed significantly among the calibration, submission, and inventory datasets (Figure 2.4; Kruskal-Wallis test statistic = 256.9, DF = 2, $p < 0.001$). The median wetland size in the calibration dataset (2.07 ha, n = 207) was over eight times larger than the inventory (0.245 ha, n = 1,782,001) and over seven times larger than the submission datasets (0.290 ha, n = 2087), and the median submission wetland size was 18.4% larger than the inventory. Based on the Dwass-Steel-Critchlow-Fligner post-hoc test for pairwise comparisons, calibration wetlands were significantly larger than the submission and inventory dataset wetlands, and the submission wetlands were significantly larger than the inventory wetlands ($p < 0.001$ between each group). Plot of residuals to observe homogeneity of variance can be found in Appendix 1, Figure 1.

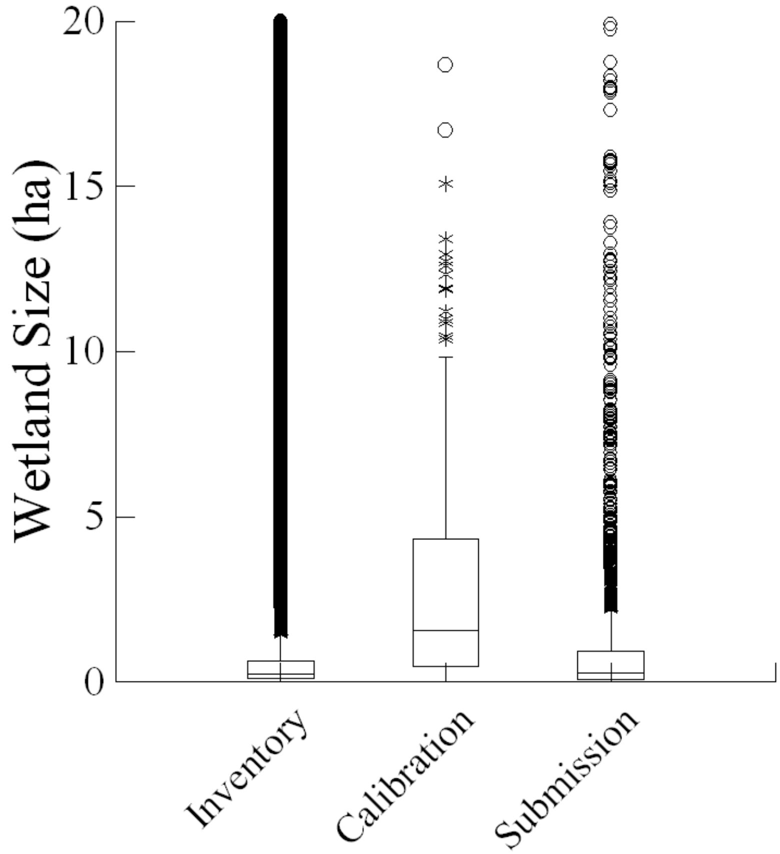

Figure 2.4: The distribution of wetland sizes in hectares for each of the Alberta Merged Wetland Inventory (inventory), calibration, and submission datasets. The Y-axis was cut off at 20 ha to better visualize differences. The amount of cases cut off were 16,042 for the inventory (0.9% of total cases), 23 for calibration (13% of total cases), and 56 for submission (2.6% of total cases). The asterisks on the plot represent outliers (> 1.5 x IQR), and the circles represent extreme outliers (> 3 x IQR).

There was a weak, but highly significant negative quadratic relationship between normalized ABWRET-A value scores and wetland size (Figure 2.5) ($r^2 = 0.011$, $p < 0.001$, $y = (2x10^{-4})x + 0.67$. Plot of residuals can be found in Appendix 1, Figure 2.

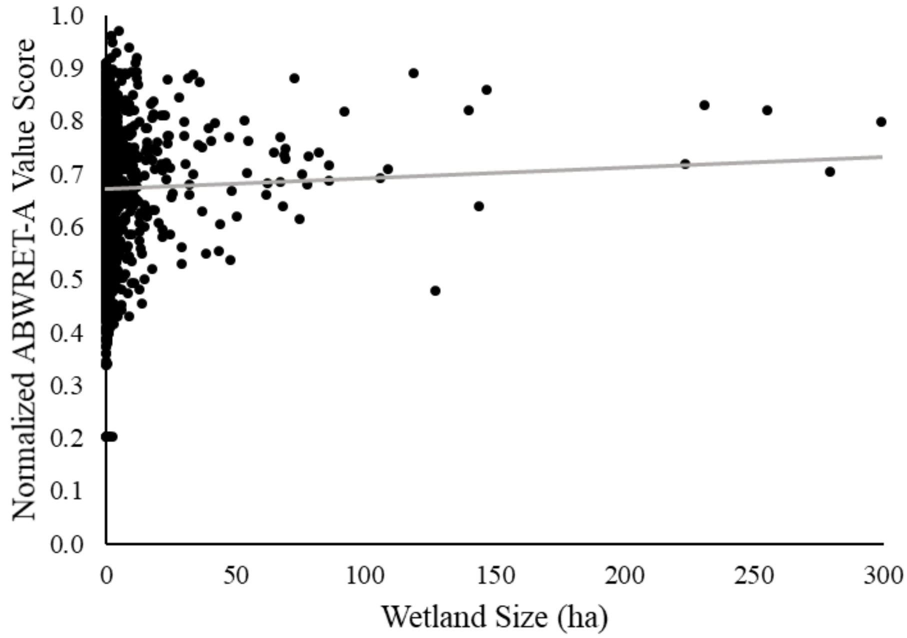

Figure 2.5: Normalized Alberta Wetland Rapid Evaluation Tool- Actual (ABWRET-A) value scores plotted against wetland sizes (in hectares) in the combined calibration and submission datasets. Nine cases were cut off (0.4% of total cases) of the x-axis to better visualize the trend.

2.3.2 Distance to Road

The calibration, submission, and inventory wetlands differed significantly in their straight-line distances from wetland to the nearest road (Kruskal-Wallis test statistic = 409.6, DF = 2, $p < 0.001$). The median straight-line distance from wetland to the nearest road was about 2.5 times closer in the calibration wetlands (162.1 m, n = 207) than the inventory wetlands (399.7 m, n = 1,782,001), and the median calibration road distance was 68% closer than the submission wetlands (median = 237.0 m, n = 2087). Further, the median submission road distance was 40.7% closer than the inventory dataset (Figure 2.6). According to the Dwass-Steel-Critchlow-Fligner post hoc test, the median road distances for the calibration sites are significantly smaller than for either the submission or the inventory wetlands, and the median submission wetlands road distance is significantly smaller than for the inventory wetlands ($p < 0.001$ between all groups). Boxplots of homogeneity of variance located in Appendix 1, Figure 3).

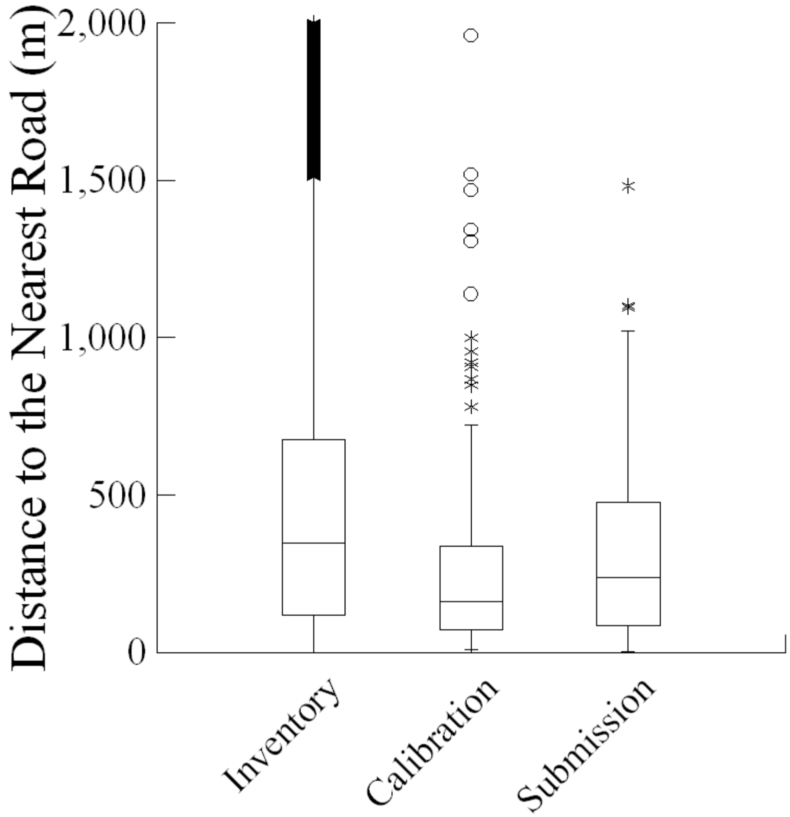

Figure 2.6: The distribution of shortest straight-line distance from wetland to the nearest road in each of the inventory, calibration, and submission datasets. The asterisks on the plot represent outliers (> 1.5 x IQR), and the circles represent extreme outliers (> 3 x IQR). The Y-axis is cut off at 2,000 m to better visualize differences in boxes. The cases cut off from the inventory were 155,085 (8.7% of total cases).

There was a weak, but highly significant relationship between normalized ABWRET-A value scores and straight-line distances from wetland to the nearest road (Figure 2.7; $r^2 = 0.0093$, $p < 0.001$, $y = (4x10^{-5})x + 0.66$). A plot of residuals can be found in Appendix 1, Figure 4.

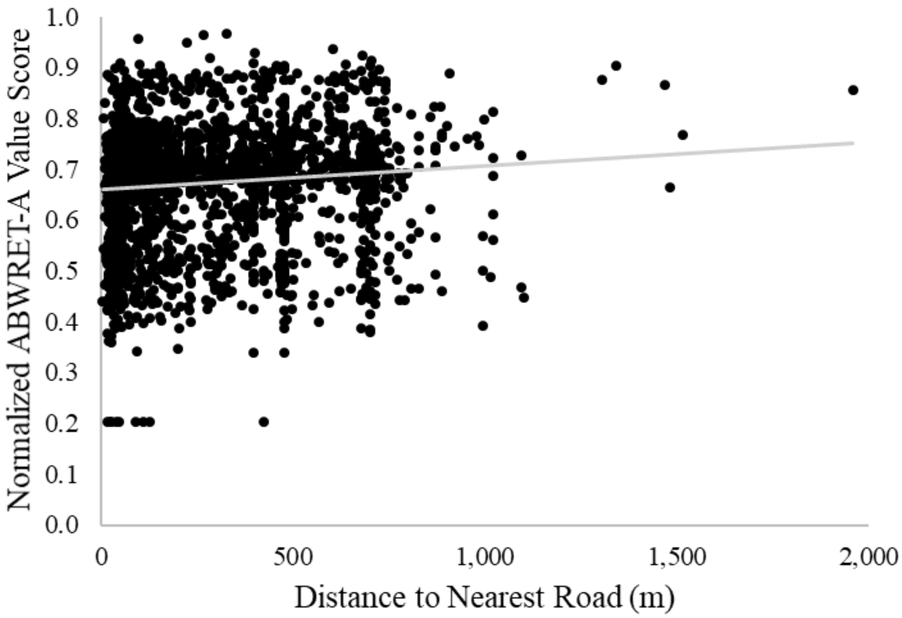

Figure 2.7: The normalized Alberta Wetland Rapid Evaluation-Actual (ABWRET-A) value scores plotted against shortest straight-line distance from the wetland to the nearest road in metres in the combined calibration and submission datasets.

2.3.3. Submission Geographic Clustering

Permitted wetland drainage was found to be concentrated around major cities in Alberta (Figure 2.8). Using the Getis-Ord Gi statistic to see how many wetland centroids were found in cells of varying sizes (6, 12.5, 25, and 50 km) covering the settled area of Alberta (Figure 2.1), statistically significant ($p < 0.01$) geographic clusters were found around both the cities of Edmonton and Calgary at each cell size. In addition to the application of the Gi statistic, the point pattern for each of the four grid sizes produced 1) a variance to mean ratio greater than 1 and 2) significant difference from a Poisson distribution using Chi-Square statistic, which further corroborate the results of the Gi statistic that the wetlands targeted for development in the submission dataset are spatially clustered around the two most populous cities in Alberta by an around order of magnitude (Statistics Canada, 2016).

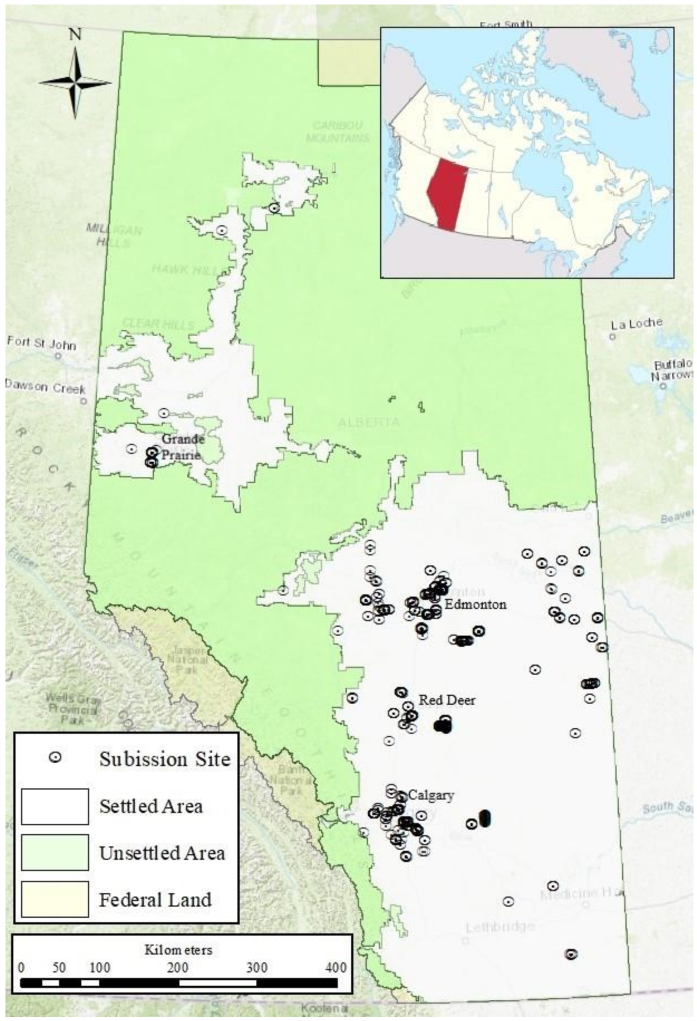

Figure 2.8: The province of Alberta, Canada, showing the point locations of all of the 2087 submission sites. The inset depicts Alberta in red in the context of the rest of Canada.

2.3.4 Wetland Type

The proportion of wetland types differed significantly between the calibration and inventory datasets (G-test statistic = 45.1, DF = 3, $p < 0.001$) (Figure 2.9). With a Bonferroni correction α of $0.05/4 = 0.0125$, the proportion of bogs (G-test statistic = 18.0, $p < 0.001$) and fens (G-test statistic = 30.4, $p < 0.001$) differed significantly, with 13.7% more fens and 5.4% fewer bogs represented in the calibration dataset compared to what the inventory suggests is present in the true population of wetlands. There was no significant difference between the proportion of swamps (G-test statistic = 1.0, $p = 0.31$) or marshes (G-test statistic = 3.5, $p = 0.061$) present between the calibration and inventory datasets.

The proportion of wetland types differed significantly between the calibration and submission datasets (G-test statistic = 174.8, DF = 3, $p < 0.001$). With a Bonferroni correction α of $0.05/4 = 0.0125$ to control for family-wise error rate, the proportion of fens (G-test statistic = 172.0, $p < 0.001$), and marshes (G-test statistic = 75.6, $p < 0.001$) differed significantly, with the calibration dataset containing 22.9% more fens, and 23.6% fewer marshes. There was no significant difference between the proportion of bogs (G-test statistic = 0.073, $p = 0.79$), and swamps (G-test statistic = 0.17, $p = 0.68$) between the two datasets.

The proportion of wetland types differed significantly between the submission wetlands and the inventory wetlands (G-test statistic = 495.0, DF = 3, $p < 0.001$). With a Bonferroni correction α of $0.05/4 = 0.0125$, the proportion of bogs (G-test statistic = 166.1, $p < 0.001$), fens (G-test statistic = 250.9, $p < 0.001$), swamps (G-test statistic = 20.1, $p < 0.001$), and marshes (G-test statistic = 359.3, $p < 0.001$) differed significantly between the submission and inventory datasets. The submission dataset contained 17.6% more marshes than the inventory, as well as 9.1% fewer fens, 5.3% fewer bogs, and 3.2% fewer swamps.

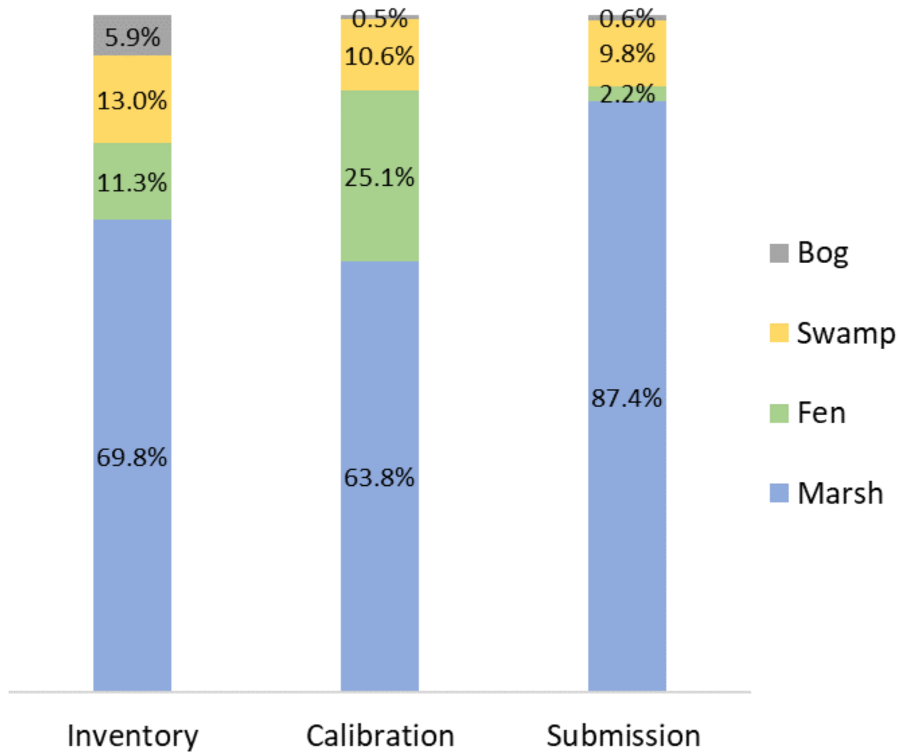

Figure 2.9: The percent representation of wetland types (bogs, fens, marshes, and swamps) observed in each of the Alberta Merged Wetland Inventory (inventory), calibration, and submission datasets.

In the combined calibration and submission datasets, the normalized ABWRET-A value scores differed significantly among the four wetland types (Figure 2.10; Kruskal-Wallis test statistic = 60.6, DF = 3, $p < 0.001$). Based on the outcome of Dwass-Steel-Critchlow-Fligner post-hoc pair-wise comparisons,, the median ABWRET-A score was largest in marshes (0.70, n = 1949), followed by fens (0.69, n = 97), then swamps (0.65, n = 225), and finally bogs (0.61, n = 14) (Figure 2.10, Table 2.1). A plot of residuals to observe homogeneity of variance can be found in Appendix 1, Figure 5).

Table 2.1: Dwass-Steel-Critchlow-Fligner post-hoc test results comparing normalized Alberta Wetland Rapid Evaluation Tool-Actual (ABWRET-A) value scores among wetland types in the combined calibration and submission datasets.

Group(i)	Group(ii)	Statistic	P-Value
Bog	Fen	62.0	< 0.001
Bog	Marsh	1275.7	< 0.001
Bog	Swamp	144.2	< 0.001
Fen	Marsh	473.0	< 0.001
Fen	Swamp	33.3	< 0.001
Marsh	Swamp	-307.6	< 0.001

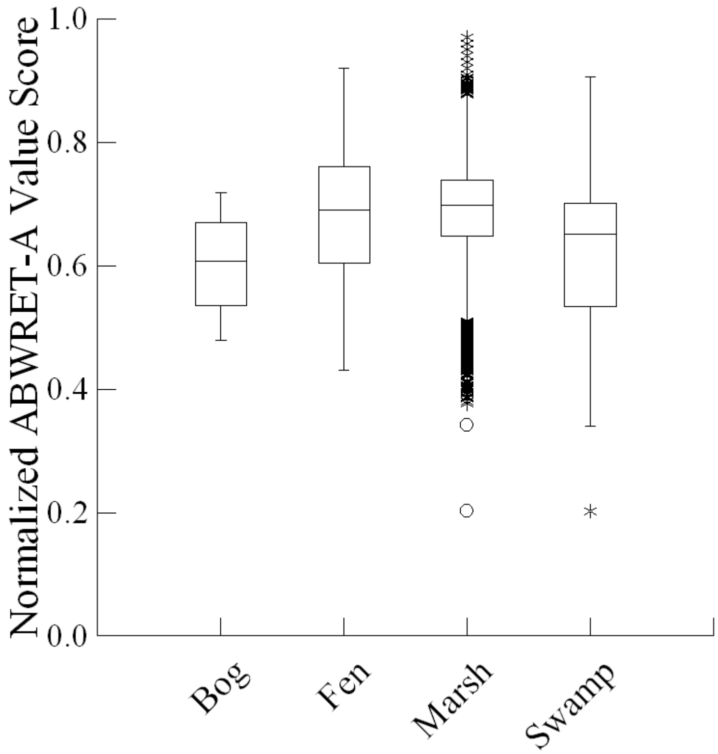

Figure 2.10: The distribution of normalized Alberta Wetland Rapid Evaluation Tool- Actual (ABWRET-A) value scores in the combined calibration and submission datasets for each of the four wetland types. The asterisks represent outliers (> 1.5 x IQR), and the circles represent extreme outliers (> 3 x IQR).

2.3.5 Permanence Class

The marshes chosen for ABWRET-A calibration were significantly different in their proportion of permanence class ranges (temporary-seasonal and seasonal-permanent) from the marshes in both the central and southern Alberta inventories (G test-statistic = 88.3, DF = 1, $p < 0.001$), and the submission dataset (G test-statistic = 91.6, DF = 1, $p < 0.001$; Figure 2.11). The classification of wetlands into the more permanent category (seasonal-permanent) was 38.4% higher in the calibration dataset than in the central and southern Alberta wetland inventories. More, it was 39% higher than the proportion of wetlands classified as the more permanent category in the submission dataset. In contrast, the proportion of marshes categorized as the more permanent class (seasonal-permanent) was equivalent between the submission dataset and the central and southern Alberta inventories (G test-statistic = 0.32, DF = 1, $p = 0.572$; Figure 2.11).

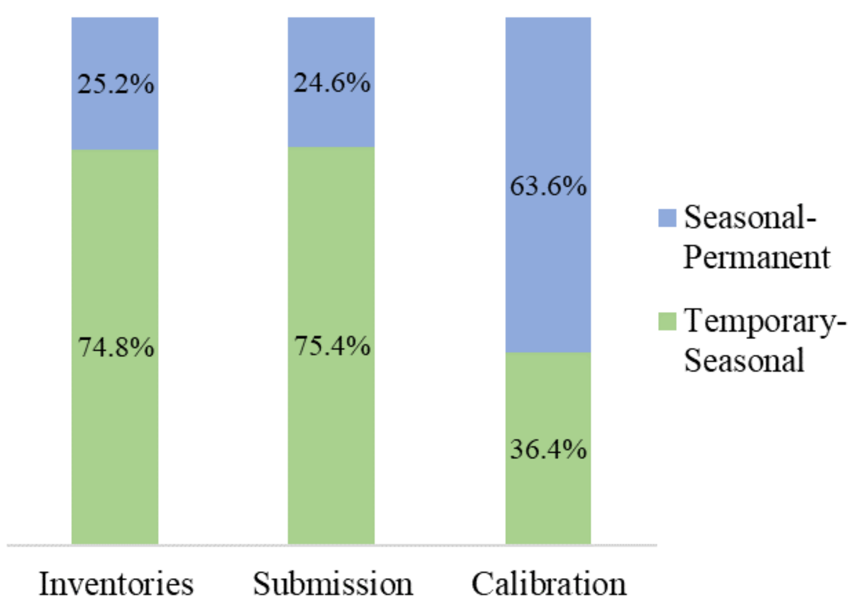

Figure 2.11: The percent of wetlands that are classified as either temporary to seasonal or seasonal to permanent as their permanence class in the central and southern Alberta inventories (inventories), submission, and calibration datasets.

Normalized ABWRET-A value scores for the combined calibration and submission datasets did not differ significantly between the wetlands classified as temporary to seasonal (median = 0.702, n = 1314) and the wetlands classified as seasonal to permanent (median = 0.699, n = 497; Mann-Whitney U test statistic = 335,199, DF = 1, p = 0.38; Figure 2.12). Plots of residuals can be found in Appendix 1, Figure 6.

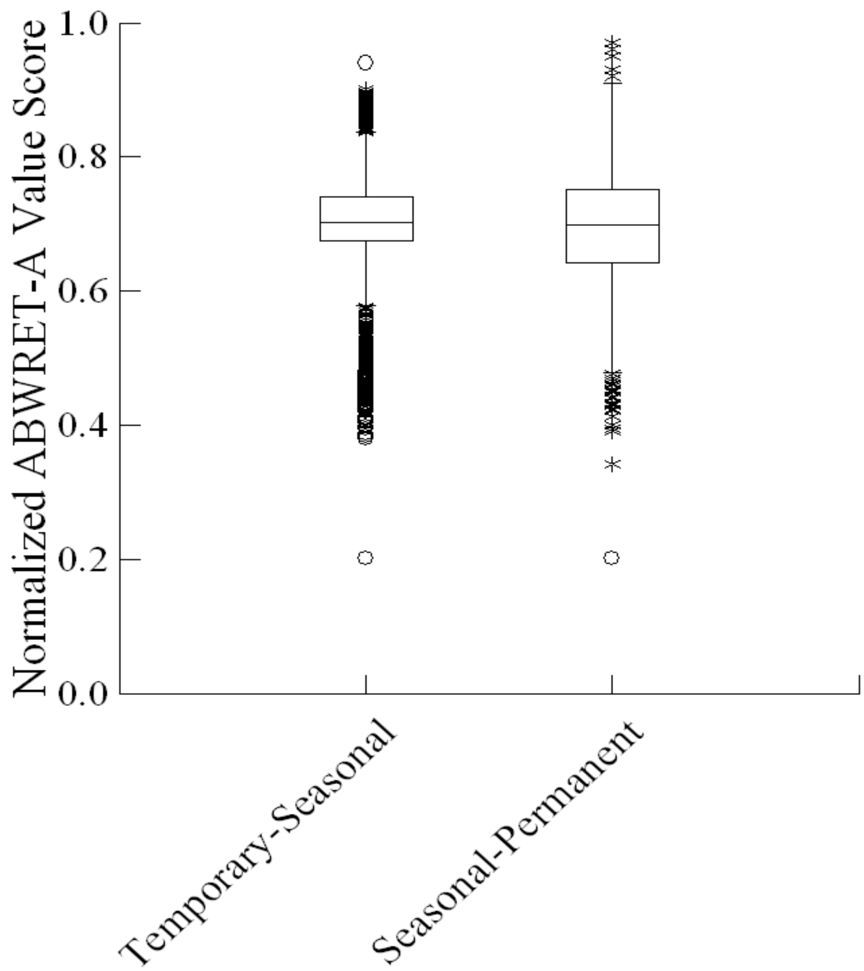

Figure 2.12: The distribution of normalized Alberta Wetland Rapid Evaluation Tool- Actual (ABWRET-A) value scores for marshes in the combined calibration and submission dataset grouped into either temporary-seasonal or seasonal-permanent. The asterisks represent outliers (> 1.5 x IQR), and the circles represent extreme outliers (> 3 x IQR).

2.3.6 ABWRET-A Score Distribution

As expected, the distribution of ABWRET-A scores of the calibration wetlands conformed to the distribution mandated by the ABWRET-A manual prior to application of the modifier based on area of historic wetland (G test-statistic = 0.0088, DF = 3, $p = 1.0$) (Figure 2.13).

In contrast, the distribution of pre-modified ABWRET-A scores in the submission dataset differed significantly from the ABWRET-A manual recommendation (G test-statistic = 817.2, DF = 3, $p < 0.001$; Figure 2.13). With a Bonferroni correction α of 0.05/4 = 0.0125, the proportion of A's (G = 238.0, $p <0.001$), B's (G = 399.5, $p < 0.001$), and D's (G = 482.7, $p < 0.001$), differed significantly from the manual recommendations. Only the proportion of C's in the submission dataset conformed to the manual's required proportions (G = 0.19, $p = 0.66$).

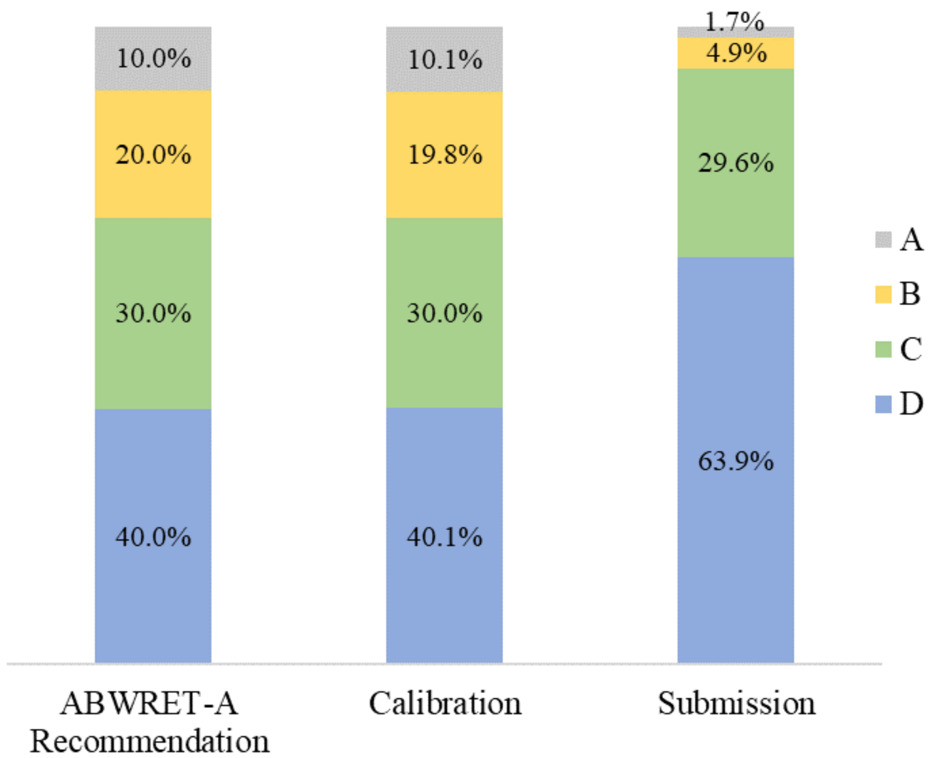

Figure 2.13: Percent representation of each pre-modified (before area of historic loss modifier) Alberta Wetland Rapid Evaluation Tool-Actual (ABWRET-A) score in the calibration and submission datasets compared to the recommended distribution of scores (from: Government of Alberta, 2015).

2.4 Discussion

2.4.1 ABWRET-A Calibration Biases and effect on scoring

Wetland rapid assessment tools may help conserve high functioning wetlands, prioritize degraded wetlands for restoration, and impose effective economic disincentives to promote sustainable development. However, if tools are inaccurate or biased in scoring wetlands, then they may undermine wetland policy and the public's trust. ABWRET-A is used to estimate the value of any wetland in Alberta in a standardized way, however, no validation of this tool has been done, i.e., the scores representing different functions have never been compared to direct measures of those functions. The tool was, however, calibrated. Meaning that the scoring equations were tuned to yield the desired distribution of scores and provision of wetland functions present in the natural population of wetlands in Alberta. Comparing the calibration dataset to the population of wetlands in Alberta can confirm whether the calibration of the tool is likely yielding the desired distribution of scores in its implementation I set out to test for any bias in terms of wetland size, distance to road, wetland type, or marsh permanence class in ABWRET-A calibration site selection. I further sought to determine what effect such biases could have on ABWRET-A scoring to determine whether it is likely the tool is under- or overestimating the contribution of assessed wetlands to local ecosystem services. I asked questions comparing the distribution of these wetland features between the calibration wetlands and the inventory, which represents the natural variability of wetlands in the settled area of Alberta (Figure 2.1), the area of my study's focus. I also compared features between the calibration wetlands and the wetlands targeted for permitted loss in the submission dataset. The calibration dataset should be representative to both the inventory and the submission dataset or it runs the risk of both misrepresenting the natural population of wetlands in the study area and not properly representing the wetlands being targeted for permitted loss, potentially affecting ABWRET-A's ability to inform wetland conservation and appropriate fee structures for in lieu payments (Table 1.2).

The calibration wetlands tended to be larger than both the inventory and submission wetlands (Figure 2.4), and there was a weak, but significant relationship between wetland size, and normalized ABWRET-A value score (Figure 2.5). With such a large sample size (2,294 wetlands in the combined calibration and submission datasets), I recognize that I have a high power to detect perhaps trivial relationships. However, given the large number of wetlands being permitted for drainage, even a slight difference in scoring can amount to a large influence at the scale of the wetlandscape. The seemingly positive influence of wetland size on normalized ABWRET-A score could be due to several factors. One being that one of the ABWRET-A scoring inputs gives higher scores to wetlands greater than 10 ha in area (Government of Alberta, 2015). Also, though there is some evidence that smaller wetlands are no less important than larger wetlands (e.g., Ghermandi et al., 2010), there is an abundance of evidence that wetland functional performance is correlated with wetland area, and so assigning higher scores to larger wetlands can be defended. For example, larger wetlands are known to collect and regulate more runoff (Evenson et al., 2018), better support avian and fish diversity (Mensing et al., 1998), and mitigate flooding (Acreman and Holden, 2013), all of which factor in to ABWRET-A scores. This may result in the much more abundant small wetlands in the landscape being undervalued by ABWRET-A (e.g., Serran and Creed, 2016), since the scores of the wetlands in the calibration dataset were used to set the ABWRET-A score conversion bins (conversion of 0-1 scale normalized ABWRET-A value score to categorical, final A, B, C, or D score). If the bin borders are set too high due to over-sampling of larger wetlands in the calibration of the tool, application of the tool to the population of wetlands in Alberta's settled area will likely underestimate their value. Adding calibration wetlands that are smaller in size and recalculating the bin borders would make the calibration wetlands more representative of both the natural population of wetlands in the settled area of Alberta, and the wetlands that are being targeted for permitted loss. A recalibration with smaller wetlands would reduce the impact of wetland size bias influencing ABWRET-A scoring.

The calibration wetlands were situated closer to roads than the majority of both the inventory and submission wetlands (Figure 2.6), and there is a weak, but significant relationship between wetland distance to the nearest road and normalized ABWRET-A value score (Figure 2.7). As was the case with larger wetlands receiving higher scores, the influence of road proximity on ABWRET-A score may be slight, but the effect can sum across the thousands of wetlands being drained under permits to create a non-trivial effect across the region. It is unsurprising that the wetlands that developers are targeting for permitted wetland development are nearer to roads, as road access is a prerequisite for most developments. My analyses did not consider road use or road intensity (i.e., a rural gravel road is not differentiated from a paved road or a divided highway), though this would likely also influence the degree of disturbance associated with proximity to a given road. Regardless, the greater proximity of calibration wetlands to roads is concerning as the scientific literature includes many studies that have found evidence of decreasing measures of wetland function with decreasing road distance (e.g., Findlay and Bourdages, 2000, Miller and Wardrop, 2006, Shulse et al, 2010, Johnson et al., 2013). Contrary to the wetland size bias, the bias in favor of wetlands near roads in the calibration dataset could cause ABWRET-A to overestimate the relative value of a given wetland, as the thresholds between bins would be artificially lowered by the bias in the calibration dataset. Adding calibration wetlands further away from roads to better represent both the natural variability of wetlands in the inventory and the wetlands that are being targeted for permitted loss would mitigate the impact of road stressors influencing calibration scores and, in extension, scores coming from ABWRET-A's use.

There were significantly more fens, and fewer bogs represented in ABWRET-A's calibration than the inventory suggests is in the natural population of wetlands in the study area, as well as significantly more fens, and fewer marshes in the calibration dataset versus the submission dataset (Figure 2.9). This suggests that developers are favouring marshes over bogs and fens, compared to the natural frequency distribution of wetland types on the landscape. Further, all wetland types differed significantly in their distributions of normalized ABWRET-A value scores, with marshes having the largest median normalized ABWRET-A value score, followed by fens, then swamps, and finally bogs (Figure 2.10). Providing higher ABWRET-A scores to marshes than other wetland types is difficult to justify and reflects the difficulty in weighing the functions provided by one wetland type against the functions provided by another. For example, marshes better support waterfowl and bird abundance and diversity (Baschuk et al., 2012, Sulaiman et al., 2015), bogs can be better at storing carbon and reducing greenhouse gas emissions (Raghoebarsing et al., 2005), fens can be better at supporting floristic diversity (Cooper, 1996) and retaining phosphorus (Prepas et al., 2011), and swamps can be good at storing and transmitting groundwater (Fitzgerald et al., 2003), all of which are functions measured by ABWRET-A that influence ABWRET-A scores. Yet there is no scientific basis for weighting the provision of carbon storage relative to phosphorus retention. Such decisions must reflect policy goals and social and economic values, which are not currently invoked in ABWRET-A scoring in a transparent or explicit manner. Nevertheless, having a higher proportion of fens sampled as part of ABWRET-A calibration than is present in the inventory and a lower proportion of bogs could set the ABWRET-A score conversion bins too high because fens score higher than bogs. This would result in underestimates of function when ABWRET-A is applied. Adding more bogs, reducing the number of fens, and even adding some more marshes to the ABWRET-A calibration sites would increase the representativeness of the calibration sites to both the natural variability of wetlands and the wetlands being targeted for permitted loss in terms of wetland type, but it would not address the issue that wetland functions are being weighed subjectively in tallying the final ABWRET-A score. One option would be to integrate more formally these scoring weights to rate functions that are deemed more critical in a given location more highly than others and would mitigate the disproportionate wetland type distribution affecting ABWRET-A scoring.

In terms of wetland permanence class, the marshes of the calibration wetlands had a much higher proportion of permanence classes in the seasonal-permanent range than in the temporary-seasonal range relative to the marshes in the central and southern Alberta inventories, and compared with the submission dataset (Figure 2.111). This is perhaps not surprising, given the preference for larger wetlands in the calibration dataset (Figure 2.4) and the correlations that have been found between wetland size and permanence class (e.g., Babbitt, 2005). Interestingly, there was no significant effect of wetland permanence class on normalized ABWRET-A value score (Figure 2.12). This was surprising as wetland permanence class directly positively influences three ABWRET-A functions (human use, fish habitat, and streamwater cooling), while negatively influencing only one (songbird, raptor, and mammal habitat) (Government of Alberta, 2015). However, despite permanence class not significantly affecting normalized ABWRET-A value scores, the larger proportion of more permanent wetlands sampled in the calibration dataset, compared with the inventory and the submission dataset, does indicate that the calibration dataset is not fully representative of the full population of wetlands in the settled area or the wetlands that are targeted by developers for permits to drain or fill.

2.4.2 ABWRET-A Scoring since Implementation

To determine if the biases made in ABWRET-A calibration are affecting how wetlands are being scored since ABWRET-A's implementation, I compared the distribution of ABWRET-A scores from both the wetlands that have been scored from the tool's implementation in the submission dataset and the wetlands used to calibrate ABWRET-A to the distribution of scores recommended by the ABWRET-A manual (Government of Alberta, 2015). Since the normalized ABWRET-A value scores (0-1 scale scores) in the calibration dataset determine which categorical A, B, C, or D score a wetland receives, it is not surprising that the distribution of ABWRET-A scores mirror each other almost perfectly between the calibration dataset and the ABWRET-A manual recommendation of scores (Figure 2.13). The submission dataset, however, contained significantly fewer As and Bs, and significantly more Ds than was recommended in the ABWRET-A manual (Government of Alberta, 2015) (Figure 2.13).

There are a couple of factors that could have caused the submission dataset to contain more Ds and fewer As and Bs relative to the recommendation (Government of Alberta, 2015). Both wetland size (Figure 2.5) and type (Figure 2.10) biases in ABWRET-A calibration would result in under-estimates of wetland function when the tool is applied, whereas the road distance bias (Figure 2.7) would result in overestimating wetland function. However, the net effect of these contrasting biases in ABWRET-A calibration could have been to under-value wetlands being evaluated for development. This could account for the lower distribution of scores of wetlands targeted for development.

Alternatively, developers may be targeting lower scoring wetlands by the happenstance of geography. The submission sites are concentrated around major cities and are distributed closer to roads than the inventory wetlands (Figure 2.6). Urbanization and associated stressors can negatively affect wetland function (Findlay and Bourdages, 2000, Miller and Wardrop, 2006, Shulse et al, 2010, Johnson et al., 2013), and so the fact that most wetland development is taking place around cities could mean that the wetlands being targeted for development just happen to be of lower function due to pre-existing impairment. However, the relationship I have found between road distance and normalized ABWRET-A value score is quite weak (Figure 2.7), whereas the differences in score distribution is quite large (Figure 2.13). Thus, the effect of geographic clustering near urban areas on the disproportionately high number of D-value wetlands in the submission dataset is likely small.

An alternative and more optimistic explanation for why the distribution of As, Bs, Cs, and Ds in the submission dataset favours lower scores compared to the calibration dataset and the policy target is that the policy is effective at discouraging development of high functioning wetlands. Developers know that the consequences for wetland drainage (monetary cost or wetland area replacement, Table 1.2) is lower for draining low-value wetlands (Government of Alberta, 2015), and so they may avoid submitting applications for removal of high-value wetlands altogether, which would mean that wetlands suspected of scoring highly do not enter into the system, e.g., Claire et al. (2011). If true, this would yield strong support for the function-based policy approach adopted by Alberta and its implementation through ABWRET-A. Presuming that the ABWRET-A scores accurately represent the level of function provided by a wetland, it would suggest the policy is effective in its objective to conserve wetlands of the highest value, as such wetlands are not represented in the applications for development permits. Unfortunately, given the biases in the calibration of the tool, it is not possible to test which of these explanations is responsible for the observed difference in the distribution of ABWRET-A scores between the calibration and submission datasets.

2.4.3 Targets for Permitted Wetland Drainage

If wetlands that are being targeted for loss are not a random subsample of the natural population of wetlands in the settled area in terms of features such as size, distance to roads, geographic area, type, and permanence class, then ecosystem services that are provided by wetlands could be affected at the regional level. The wetlands targeted for permitted loss in the first year and a half following ABWRET-A implementation in the submission dataset were on the larger end of the distribution of wetland sizes represented in the inventory (Figure 2.4). This is initially surprising, as studies have shown that wetland loss historically favours smaller wetlands (Van Meter and Basu, 2015, Serran and Creed, 2016, Serran et al., 2018). However, the inventory dataset contains many wetlands that are very small, including some smaller than 1 m^2. Most likely such small wetlands are being drained or filled in without going through the government-mandated process that includes an ABWRET-A assessment. Therefore, these small wetlands would not get included in the submission dataset. This is consistent with Clare and Creed (2014), who found that in the Beaverhill subwatershed near Edmonton, Alberta wetlands drained without a permit are typically smaller in size than those drained with a permit. Clare and Creed (2014) concluded that within their primarily agricultural landscape fully 80% of wetland loss took place without a permit. This was before the new Wetland Policy came into effect in 2013 (Government of Alberta, 2013a) and current unpermitted rates of loss or rates of unpermitted loss from elsewhere in the settled region of Alberta are unknown. Certainly, the rate of permitted wetland loss since the implementation of the new Wetland Policy is substantial, with over 2,000 wetlands drained via a permit in only the first 1.5 y of ABWRET-A implementation. Permitted wetland loss is also concentrated in areas of the highest population density in the province, where the ecosystem services provided by wetlands would benefit the most people. It seems likely that the bias toward larger wetlands in the submission dataset reflects an avoidance of the permitting process for smaller sized wetlands than it does their avoidance by developers. Future research should seek to confirm whether permitted loss is targeting larger than average wetlands, whereas unpermitted loss is disproportionately occurring with smaller sized wetlands in Alberta and more generally. Further, the wetlands that are being lost under permit are often replaced with wetlands that are larger in size (Clare et al., 2011). This implies a net loss of the provision of ecosystem services on a regional scale for small wetlands such as providing specialized habitats that are known to increase biodiversity (Richter and Azous, 1995, Semlitsch and Bodie, 1998, Leibowitz, 2003).

The wetlands in the submission dataset were also distributed significantly closer to roads than the inventory wetlands (Figure 2.6), as well as clustered significantly around the cities of Edmonton and Calgary, the two largest cities in the province by an order of magnitude (Statistics Canada, 2016). This is consistent with findings that the two main causes of wetland loss in Alberta are urbanization and agriculture (Van Asselen et al., 2013, Clare and Creed, 2014, Terando et al., 2014), where permitted loss is more often happening in developed areas, and losses in agricultural areas often go unpermitted (Clare and Creed, 2014), implying permitted loss should be found around major cities and be distributed closer to roads. Since it is known that replaced wetland area is often situated outside of the area or even watershed of drainage (Clare et al., 2011), this concentration of wetland loss around the major cities of Alberta likely means permanent loss of those ecosystem services in the area of preferential drainage. Wetlands located in or around cities are known to regulate temperatures (Song et al., 2013, Broadbent et al., 2018), improve urban biodiversity (Filazzola et al., 2019) and mitigate flooding (Ghermandi et al., 2010, Broadbent et al., 2018, Evenson et al., 2018). Flooding is an especially high concern, as models show that removing a concentration of wetlands in a small area greatly increases the risk of flooding (e.g., Ahmed, 2014, Evenson et al., 2018). Perhaps increasing ABWRET-A scores of wetlands submitted for drainage around major cities or increasing the amount of restored or man-made wetlands near cities would help to mitigate the increasing risk for urban flooding and reduce the spatial clustering of permitted wetland loss in Alberta.

The wetlands in the submission dataset had a significantly higher proportion of marshes, and significantly lower proportion of fens, bogs, and swamps than the inventory dataset (Figure 2.9). If these wetlands are not being replaced, as developers have the option to pay an in-lieu fee for wetland drainage that can go towards non-restorative efforts (Government of Alberta, 2013a), and it is noted that restored wetlands in Alberta are often of a different type than the wetlands they are intended to replace and outside of the watershed where the loss occurred (Clare et al., 2011), then these wetland functions are lost permanently. For marshes, they are known to better support waterfowl and bird abundance and diversity (Baschuk et al., 2012, Sulaiman et al., 2015), and export organic nutrients (D'Amore et al., 2010). This disproportionate drainage of wetland types can lead to an imbalance as the ecosystem services they provide are disproportionately lost and not replaced.

Though the submission dataset represents only 0.12% of the total wetlands in inventory, indicating only a small fraction of the wetlands in the settled area of Alberta are being targeted for development, the submission dataset includes data from only one and a half years following ABWRET-A implementation. The losses will be cumulative, and we can project that hotspots of loss like the areas surrounding Calgary and Edmonton will become depleted in wetlands over time. Continuing loss of wetland area could lead to significant changes in the landscape and thus effect how ecosystem services are provided on a regional scale, particularly given their spatial concentration. An assessment of the cumulative effects of wetland loss on an area should be performed to inform both wetland management practices and restoration techniques (e.g., Bedford, 1999).

2.5 Conclusions

Statistically significant biases are present in the selection of wetlands used for ABWRET-A calibration, as the calibration wetlands are not representative to either the provincial inventory or the wetlands being targeted for permitted loss in terms of their size, distance to the nearest road, type, and permanence class. Further, it appears that these biases in selection of calibration wetlands affects ABWRET-A scoring, as both the size and type biases result in reduced scoring for wetlands under evaluation, while road proximity bias results in increased scores for wetlands under evaluation. The net effect of these biases is unknown but could result in wetlands under consideration for a permit to drain or fill receiving lower ABWRET-A scores than they warrant. Substantiating this concern, fewer A's and B's and more D's were represented in the submission dataset than in the calibration sites, which met the distribution of scores recommended in the ABWRET-A manual. Amending the biases in the calibration dataset by sampling additional small wetlands, with shorter hydroperiods, situated further from roads, particularly marshes and bogs, would ensure that the calibration sites used to convert normalized scores to the A-D letter grades better represent both the natural variability of wetlands in the settled area of Alberta, and the wetlands that are being targeted for permitted loss. This should increase the accuracy of ABWRET-A scores given out to wetlands submitted for permits and test whether developers are preferentially developing on low value wetlands, and that ABWRET-A is, in fact, helping the Alberta Wetland Policy meet its objective of protecting the most valuable wetlands.

It also appears that preferential permitted loss is taking place for marshes that are larger, distributed closer to roads, and that are concentrated around major cities than is present in the natural population of wetlands. This implies a loss of the provision of certain ecosystem services on a regional scale, particularly in peri-urban areas. More research should be done to determine the effects of wetland loss on the regional provision of wetland functions and ecosystem services, and how that can fit into strategic wetland management to protect wetland features that have been historically targeted for loss. This would help protect the balance of wetland features and make sure that all wetland ecosystem services are protected and maintained, as different wetland features provide different ecosystem services (e.g., Clarkson et al., 2013).

3 Conclusions/Recommendations

Despite the valuable services that wetlands provide (de Groot et al., 2012), wetlands continue to be drained and removed globally (Zedler and Kercher 2005). Alberta, Canada is no exception, as wetland loss continues to happen (Alberta Water Council, 2008), with urbanization and agriculture cited as the main causes of wetland loss in the province (Bartzen et al. 2010, Van Asselen et al., 2013, Clare and Creed, 2014, Terando et al., 2014).

To try and mitigate negative impacts to wetlands in Alberta, a provincial policy was implemented (Government of Alberta, 1993, Government of Alberta, 2013a). The objectives of the Alberta Wetland Policy are 1) protecting the most valuable wetlands, 2) conserving and restoring wetlands in areas of high historic loss 3) avoiding, minimizing, and replacing lost wetland value, and 4) managing wetlands in consideration of their regional context (Government of Alberta, 2013a).

Implementation of the Alberta Wetland Policy necessitates a tool to evaluate ‘relative wetland value’ to meet these policy objectives, particularly that of protecting the most valuable wetlands (Government of Alberta, 2013a). This tool, the Alberta Wetland Rapid Evaluation Tool- Actual (ABWRET-A) was implemented in 2015, and revised in 2016 (Government of Alberta, 2016) as a standardized way to evaluate any wetland in Alberta and estimate its relative value. The goal of my thesis was to investigate how well ABWRET-A is helping achieve the Alberta Wetland Policy objectives and to investigate how the ABWRET-A tool is being used to determine which wetland features are being targeted for permitted drainage or infilling and the effect this might have on the regional provision of ecosystem services.

In brief, I detected significant biases in the sample of wetlands used to calibrate the ABWRET-A tool. Namely, these calibration wetlands were larger, distributed closer to roads, and more permanently ponded than both the natural distribution of wetlands in the area and the wetlands that have been targeted for permitted loss under the provincial policy. The calibration sites were also not representative of wetland type distribution in both the natural population of wetlands and the wetlands targeted for permitted loss, having significantly fewer bogs, and more fens than the natural population of wetlands, and fewer marshes, and more fens, than the wetlands that have been targeted for permitted loss since ABWRET-A implementation.

These biases and lack of representation may have important ramifications because I also detected a significant positive relationship between wetland size and ABWRET-A value score, and that fens scored higher than bogs. Hence, the bias in the calibration wetlands may cause wetlands being assessed to score higher or lower than is warranted to achieve the policy objectives.

Possibly substantiating concerns that the ABWRET-A tool might underestimate wetland values, the wetlands that underwent the ABWRET-A scoring procedure since the tool's implementation have significantly more D's, and fewer A's and B's than the ABWRET-A manual dictates should be assigned to the population of wetlands in Alberta. Alternatively, this might be evidence that the policy is effective in directing developers to avoid developing wetlands of the highest value (As) and redirecting them toward developing lower value wetlands (Ds).

It is well understood that when wetland functions benefits people, they are deemed wetland value (Gren et al., 1994, Whigham 1997, Woodward and Wui, 2001, Brander et al., 2006). Consequently, the regional loss of certain wetland features and associated functions should increase the value of that function, if it is becoming increasingly rare. The concentration of permitted wetland loss around major cities is probably not surprising, but it should be alarming, as models have shown that wetland loss concentrated in certain areas can increase the risk of flooding (Ahmed, 2014, Evenson et al., 2018), and major floods can cost billions of dollars in damage (e.g., Parrett and James, 1993, Pomeroy et al., 2016). The current policy attempts to curtail additional wetland losses within areas of high historic loss using a score modifier, but clearly this is not a strict enough penalty to deter developers from draining and filling more wetlands in peri-urban areas.

My policy-relevant research in evaluating the implementation of ABWRET-A in its first year and a half of application has yielded four recommendations (Table 3.1). I submit that if these recommendations are adopted, it will increase the probability of ABWRET-A supporting the achievement of the Alberta Wetland Policy objectives (Government of Alberta, 2013a). If my recommendations are not followed, then there is a significant risk that the policy objectives will fail to be met.

Table 3.1: Recommended changes to ABWRET-A based on my findings

Recommendation	**Rationale**
Adjust the pool of calibration wetlands to better match both natural population of wetlands and wetlands targeted for permitted drainage.	The current calibration wetlands are significantly larger, distributed closer to roads, and more permanently ponded than both the natural population of wetlands, and the wetlands being targeted for permitted drainage, and misrepresentative of wetland type to both. With significant relationships found between those features and ABWRET-A scoring, ABWRET-A would be more accurate in scoring wetlands with a more representative calibration pool.
Increase value score for wetlands containing features consistent with	I have found bias for wetlands being lost that are smaller, and more marshes than the natural population of wetlands. Replaced wetland area often does not reflect the lost wetlands, implying a

those being lost historically.	permanent regional loss of ecosystem services provided by the lost wetlands.
Increase value score for wetlands in more populated areas and prioritize wetland conservation and restoration around cities.	Significant geographic clusters of permitted wetland drainage were found around the cities of Edmonton and Calgary. Clustered wetland loss is shown to increase risk of flooding, and urban wetlands provide value outside of flood control (e.g., Song et al., 2013, Broadbent et al., 2018, Filazzola et al., 2019).
Model the influence of wetland loss on the hydrologic network within the watershed, using a model like SWAT.	The Soil and Water Assessment Tool (SWAT) is already used in parts of Alberta (e.g., Faramarzi et al., 2015) and, if considered with ABWRET-A, would allow for implementing regional consideration of wetland management if removing a wetland can be shown to increase flood risk in an area of value.

Each recommendation in Table 3.1 is made to help ABWRET-A in different ways. Adjusting the pool of calibration wetlands to be more representative of the natural population of wetlands in the area might be time-consuming and costly, but it is also a very important step in improving ABWRET-A's ability to accurately score a wetland. This could be done in a combination of two ways. The first way would be to sample new wetlands to add to the existing calibration dataset that are bogs or marshes, smaller than 0.25 ha in area, in a more remote, undisturbed location away from any major roads, and that are either temporarily or seasonally ponded. The second option is to include some of the ABWRET-A wetland data that has already been collected in the submission dataset that are similar to those features mentioned above. In adding new calibration wetlands or using pre-existing ABWRET-A data in the submission dataset to make the calibration pool of wetlands more representative to the wetlands in the area, the different wetland features effecting ABWRET-A score could be inconsequential on the calibration of ABWRET-A, and improve the ability of ABWRET-A to accurately score a wetland.

Next, increasing ABWRET-A value scores for wetland features that are being disproportionately targeted for loss can help maintain the balance of ecosystem services provided by wetlands on a regional level. In a manner similar to the adjustment of ABWRET-A score for wetlands located in areas that have experienced high historic loss rates, wetland features being disproportionately targeted for loss (e.g., marshes; Figure 2.9) could have their ABWRET-A scores increased by one letter grade, especially if this disproportionate loss continues to happen.

Further, increasing ABWRET-A scores or prioritizing wetland construction and restoration around populated areas could be very beneficial in reducing the risk of flooding in cities. Though some cities are more prone to flooding than others, flooding near cities can cost billions of dollars of damage (e.g., Pomeroy et al., 2016). As of now, distance to a populated area is only considered in ABWRET-A calculations as a stressor (Government of Alberta, 2015), but including the already-measured distance to a populated area in a way to increase ABWRET-A score would help conserve the amount of urban wetlands and all of their benefits (e.g., Song et al., 2013, Broadbent et al., 2018, Filazzola et al., 2019) in a proactive way to reduce high-damage urban flooding.

Finally, in addition to increasing ABWRET-A scores near urban areas, introducing a hydrological model like the Soil and Water Assessment Tool (SWAT) in management decisions could help in reducing urban flooding. Using a model like SWAT, that is already used in parts of Alberta (e.g., Perez-Valdivia et al., 2015), one wetland can be removed to observe how water quantity and peak flow rate is affected in the watershed downstream (Neitsch et al., 2011). If introduced in wetland management decisions alongside ABWRET-A, urban flooding risks can be minimized in the future.

Regardless of ABWRET-A's ability to accurately estimate relative wetland value, another question arises from the policy objective of protecting the most valuable wetlands: Are the most valuable wetlands being protected? My data for analysis was restricted to accepted permit applications for wetland drainage, but personal communication with Matthew Wilson, a member of the Alberta Environment and Parks Wetland Policy implementation team (2017) has informed me that no application for wetland removal has been denied, and that all applicants have taken the in-lieu fee option as penalty instead of wetland area replacement. By using ABWRET-A scores, the policy directive should discourage developers from developing wetlands that rank as most highly valued (A) by applying higher replacement ratios that increases fees for development on high value wetlands (Government of Alberta, 2018, Figure 1.3, Table 1.2). However, it remains uncertain whether the deviation from desired proportions of A, B, C, and D scoring wetlands that I observed in the submission dataset was because the in lieu fee payments and replacement ratios are an effective deterrent to developers, and thus resulting in fewer As and more Ds being submitted for permits to drain or fill in. It could equally be that the ABWRET-A tool is simply underscoring wetlands due to biases I revealed in the size, proximity to roads, and type of wetland that were present in the calibration dataset.

In addition to the four recommendations I make for improving ABWRET-A, my thesis research has also yielded five recommendations for future research to help validate this tool and increase the accuracy of value estimation as much as possible (Table 3.2). More research needs to be done for the continued review and improvement of this tool.

Table 3.2: Suggestions for future research directions

Suggestion for future research	**Description**
Evaluation of ABWRET-A implementation in the rest of the province	Now that ABWRET-A applies to the whole province of Alberta, a similar investigation should be performed for the area of the province outside the settled area.
Analysis of more recent ABWRET-A submissions	My analysis of ABWRET-A submissions for drainage was restricted to data from 2016 to June 15th, 2017. An analysis of more recent data could update the conclusions of my research regarding trends in permitted wetland drainage.
Validation of ABWRET-A function estimates.	ABWRET-A only estimates functional performance, often via indicators, and has never undergone a formal validation of the accuracy of these estimates. These estimates should be tested against direct measures of wetland function in a formal validation of ABWRET-A.
Evaluation of ABWRET-A sensitivity in determining score	Though ABWRET-A gives only one of four categorical scores, I noticed the continuous numerical scores coming from the tools use before conversion to categorical score were very small in actual range versus their theoretical range. If the actual scores only capture a small portion of the theoretical range in score, then the tool has less resolution to discriminate between high and low function wetlands. An inquiry should be made into how ABWRET-A can better capture the extent of theoretical range of scores.
Inquiry into cause of low scoring submission sites	I found significantly fewer A's and B's and significantly more D's given to wetlands accepted for permitted drainage compared to what the distribution should be as recommended by the Government of Alberta. An inquiry should be done if ABWRET-A is underestimating score, if developers are avoiding development

	on high-value wetlands, or if developers are under-rating the value of their proposed development sites.

As development continues in Alberta, it is necessary to continue the implementation of policy, and review and improve the tools that help them. My findings show some flaws in ABWRET-A that can easily be fixed to help improve the tool's ability to accurately estimate wetland value, and encourage the Government of Alberta to continue to strive to meet the Wetland Policy objectives through ABWRET-A.

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Appendix 1: Plots of residuals for statistical tests

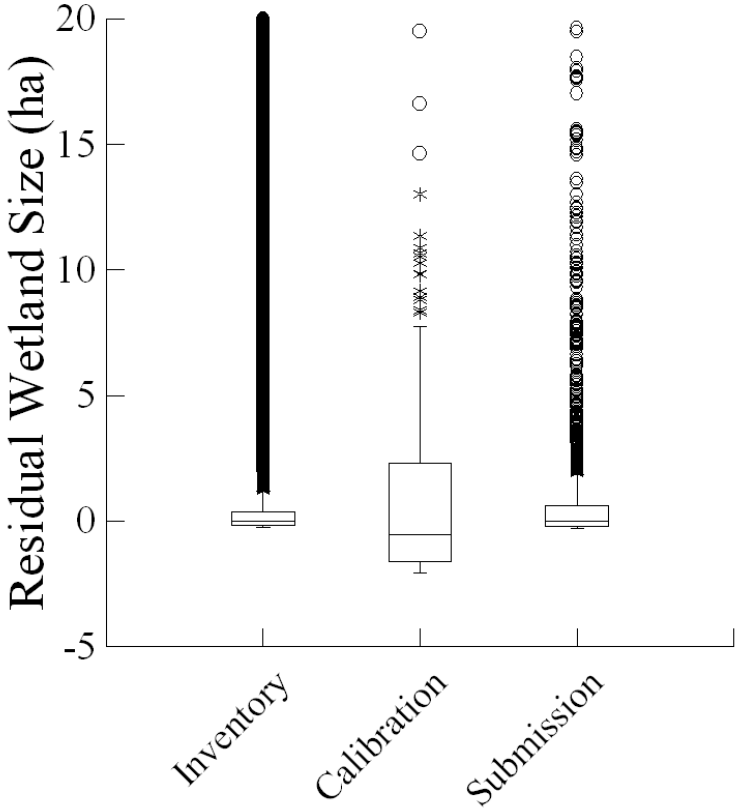

Figure 1: Residuals of wetland sizes for each of the Alberta Merged Wetland Inventory (inventory), calibration, and submission datasets. The asterisks on the plot represent outliers (> 1.5 x IQR), and the circles represent extreme outliers (> 3 x IQR).

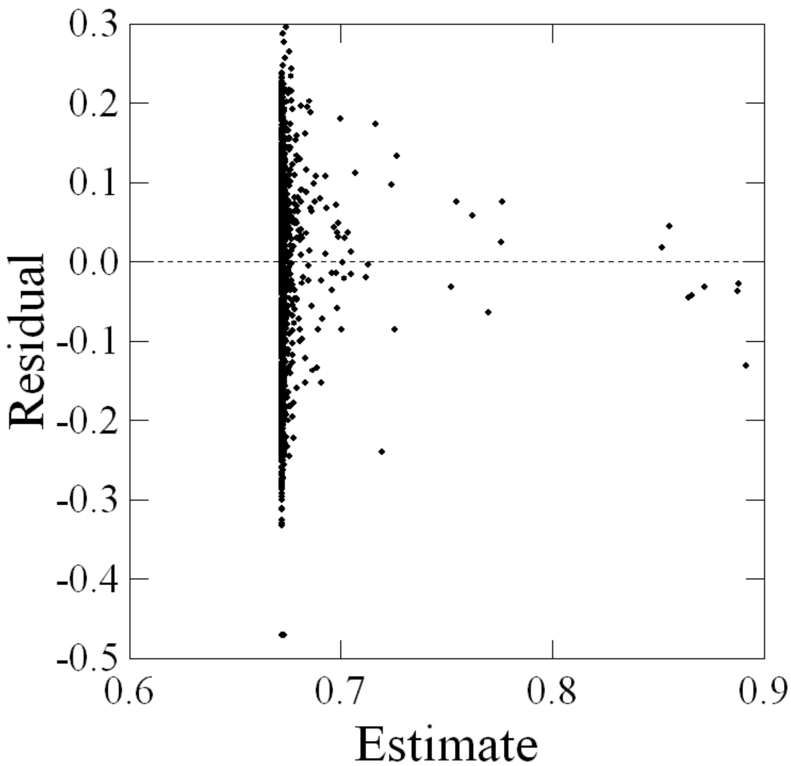

Figure 2: Residuals plotted vs. fitted values for wetland sizes vs normalized Alberta Wetland Rapid Evaluation Tool-Actual value score in the combined calibration and submission dataset.

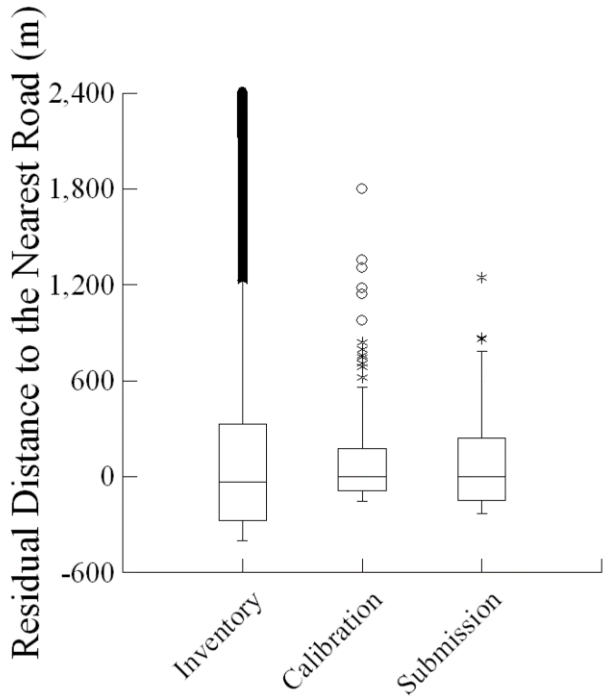

Figure 3: Residuals of shortest straight-line distance from wetland to the nearest road at each of the Alberta Merged Wetland Inventory (inventory), calibration and submission datasets The asterisks on the plot represent outliers (> 1.5 x IQR), and the circles represent extreme outliers (> 3 x IQR).

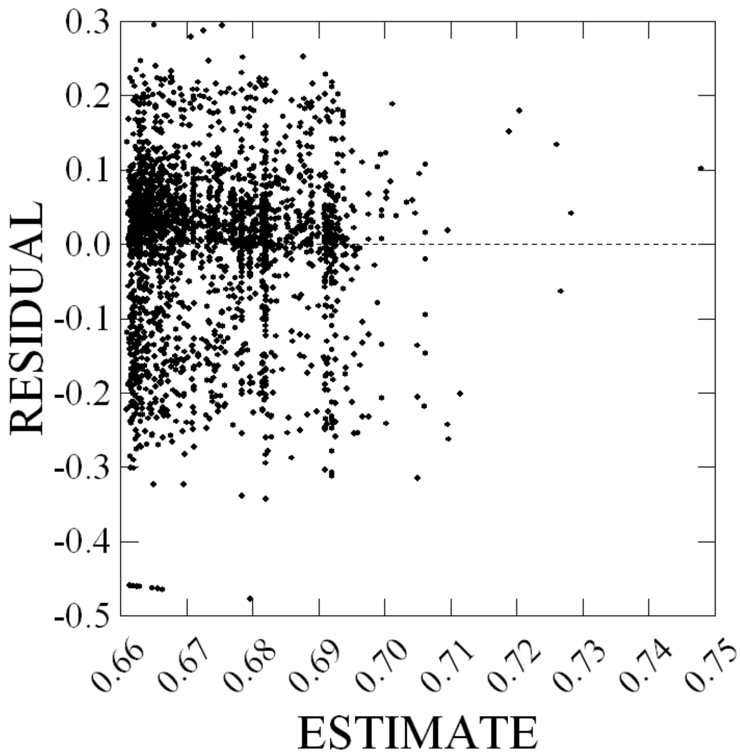

Figure 4: Residual vs fitted values of shortest straight-line distance from wetland to the nearest road plotted against normalized Alberta Wetland Rapid Evaluation Tool-Actual value scores in the combined submission and calibration dataset.

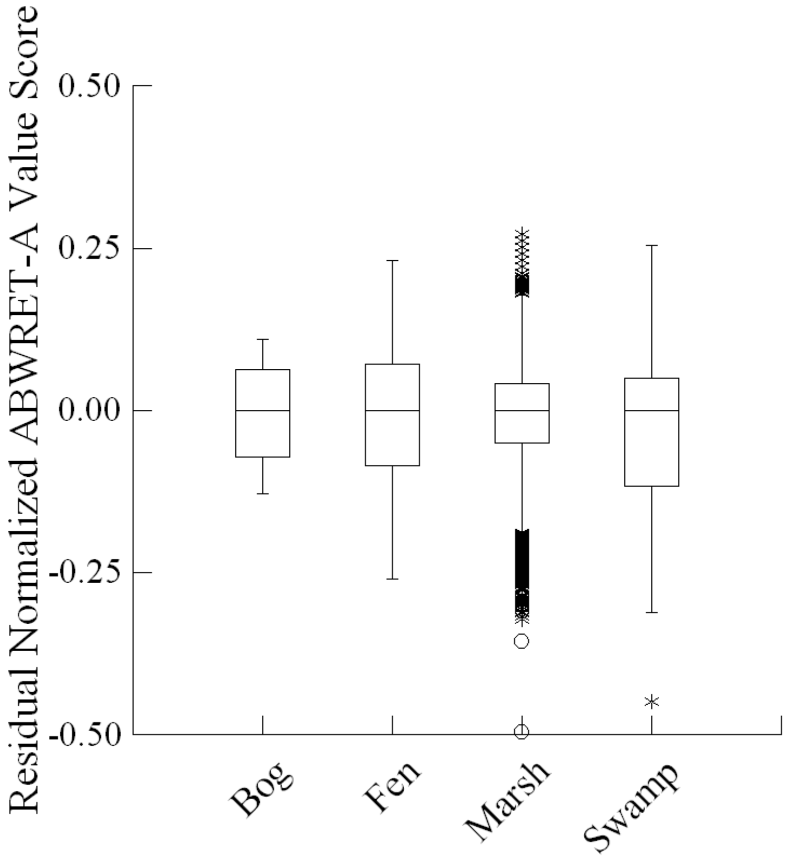

Figure 5: Residual normalized Alberta Wetland Rapid Evaluation Tool-Actual (ABWRET-A) value score at each of the four wetland types classified by ABWRET-A using the Alberta Wetland Classification System (ESRD, 2015). The asterisks on the plot represent outliers (> 1.5 x IQR), and the circles represent extreme outliers (> 3 x IQR).

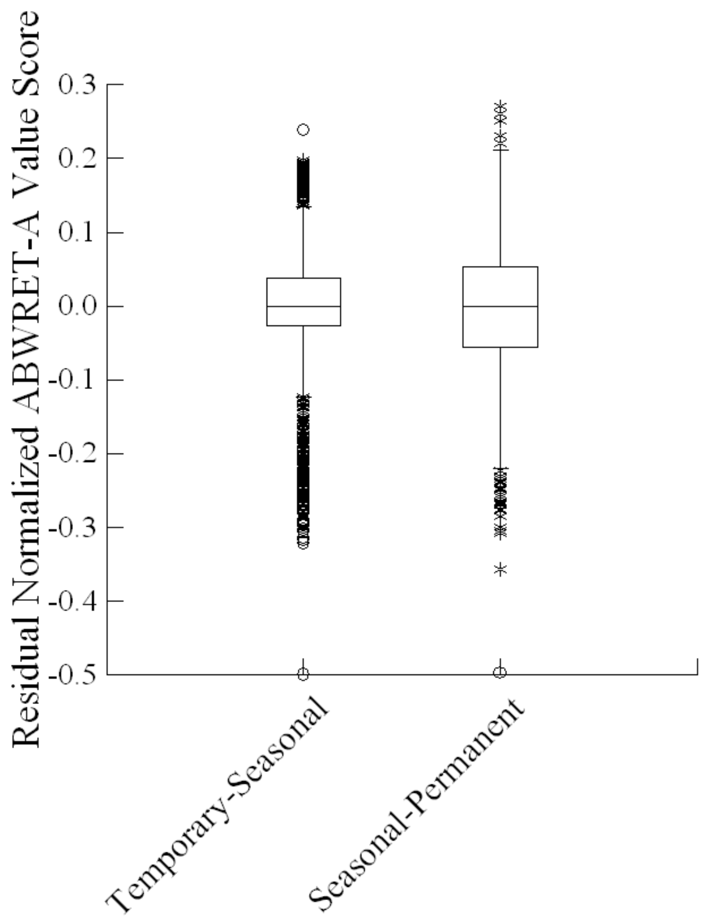

Figure 6: Residual normalized Alberta Wetland Rapid Evaluation Tool-Actual (ABWRET-A) value score at each wetland permanence class range in the combined calibration and submission dataset. The asterisks on the plot represent outliers (> 1.5 x IQR), and the circles represent extreme outliers (> 3 x IQR).