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ORIGINAL PAPER

Tracking wetland loss to improve evidence-based wetland policy learning and decision making

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Abstract At the core of any evidence-based policy analysis are accurate data and the policy analytic capacity of government agencies to use these data to develop and measure metrics of policy success. This study evaluated the government's policy capacity to manage wetlands in Alberta, Canada, by measuring and evaluating three policy metrics: (1) no net change of wetland area; (2) permitted versus unpermitted wetland loss; and (3) an information tracking system that provides credible regulatory oversight. Using a climate-corrected wetland loss inventory, we detected the loss of 242 wetlands, totaling 71 ha, in the Beaverhill subwatershed between 1999 and 2009. The majority of the losses occurred on land that were classified as 'developed' (urban and industrial) or 'agriculture'. When wetland loss was compared to government-issued wetland permit data, we found that over 80 % of the wetland area was lost without a government permit. The wetland permit data also revealed serious problems with information tracking by both government and non-government agencies responsible for policy and regulatory oversight. In order to resolve these common policy failures, governments need to commit more resources towards acquiring, effectively managing, and freely sharing information that can be used to evaluate policy outcomes to 'open up' wetland management and decision making to include active participation from informal institutions, local governments, and the general public as a means to drive improved regulatory oversight.

Keywords Wetland · Conservation · Policy analytic capacity · Inventory · Compensation · Alberta · Remote sensing

Introduction

In most jurisdictions, public policy is at the cornerstone of environmental and natural resource management. While the process of policy making is complex and includes a multitude of actors and interests across time and space, it is generally characterized by the identification and conceptualization of a problem, and the formulation, implementation, and evaluation of solutions (Sabatier 2007). A critical and often overlooked component of this process is the periodic evaluation or analysis of policy outcomes, which can uncover barriers, unintended outcomes, or unsuccessful aspects

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of policy implementation. Such analysis and review allows policy actors to reconceptualize both the policy problem and its solutions, thereby leading to policy learning that can result in more effective management outcomes (Hessing et al. 2005).

In an effort to improve the success of public policy, there has been a strong move towards policy-making and policy-analysis that is more evidence-based (Howlett 2009). The improved success of such evidentiary policy analysis, however, is largely dependent upon the policy analytic capacity of organizations or agencies that are responsible for public policy-making. Policy analytic capacity is the ability of policy actors to "collect appropriate data and utilize it effectively in the course of policy-making activities" (Howlett 2009). Thus, a prerequisite to evidence-based policy-making and analysis is an agency or organization that has the resources (both financial and human) to collect, aggregate, and interpret relevant information, and to use this information to enhance policy success over the medium- and long-term (Howlett 2009; Howlett and Joshi-Koop 2011).

While many jurisdictions strive to produce evidence-based environmental or natural resource policy, and commit to regularly conducting evidentiary policy-analysis, many fall short because they lack the institutional capacity to execute such tasks. This lack of policy analytic capacity can lead to the development of inadequate or ill-conceived policy, or failures that go undetected or unresolved, which has serious implications for the environmental and natural resources that such policies were designed to manage. Water resource management is one area of environmental management where government policies and decision making has come under increased scrutiny and criticism. In Canada, concerns over water quality and quantity, aquatic habitat loss and species declines, non-native species invasions, and increasing risks of drought and flooding resulting from changing climatic regimes, are just some of the issues facing water managers across the country. The increasing withdrawal of the federal and provincial governments from the regulation of water resources, in favor of delegating responsibility for water governance to non-state actors, has also brought forward questions concerning the institutional capacity of government to effectively regulate and manage water resources (Bakker and Cook 2011; Hutchings et al. 2012).

This study presents an evidence-based analysis of wetland policy outcomes in Alberta, Canada, and highlights the critical need for, and importance of, building policy analytic capacity in wetland management. In 1993, the government of Alberta introduced a wetland policy to manage wetlands in the central and southern portions of the province. Despite being one of the first provinces in Canada to adopt a wetland policy, to date, the government has never critically evaluated policy outcomes, despite a stated commitment to do so every 5 years (Alberta Water Resources Commission 1993). This lack of policy evaluation is despite the fact that the government has been actively engaged in developing a new provincial wetland policy since 2008, and is positioned to benefit greatly from policy evaluation. While Alberta adopted a wetland policy in 1993, it wasn't until 1999 that the government introduced the *Water Act*, which created a legislative requirement to obtain a permit to conduct activities that negatively impact wetlands. Therefore, we evaluated wetland policy outcomes in central Alberta between 1999 and 2009, as this allowed us to critically examine compliance with the legal requirement to obtain a permit prior to impacting a wetland.

Three metrics were used to evaluate wetland policy success. The first metric was no net change in the area of naturally occurring wetlands. One of the stated intents of the current wetland policy is "to conserve slough/marsh wetlands in a natural state" (Alberta Water Resources Commission, p. 3). Further, the adoption of a hierarchical mitigation sequence that prioritizes impact avoidance over minimization and compensation implies a goal of maintaining wetland area (Alberta Water Resources Commission 1993). Thus, we considered no net change of wetland area to be a key metric for measuring policy success, and quantified the total number and area of natural wetlands lost in the study area by major land use. The second metric was the number and area of wetlands that were legally drained (i.e., lost with a permit) versus illegally drained (i.e., lost without a permit). The third metric was the capacity of regulatory agencies to accurately keep track of wetland permit information, and we examined permit data from three different sources to compare information tracking, in an effort to determine whether the government has the capacity to provide credible regulatory oversight in regards to wetland management.

While this study specifically examines wetland loss in Alberta, Canada, it focuses on critical issues of policy capacity that are common in other jurisdictions that lack the resources to develop evidence-based natural resource policy. This study highlights the critical need for reliable natural resource inventories that can be used to track changes in natural resource quantity and/or quality. Such information can then be used to feed back into the policy process to improve the design and implementation of policies, and ultimately, policy outcomes.

Study area

The Beaverhill subwatershed covers an area of approximately 4,405 km^2 in central Alberta and is located in the boreal forest and parkland natural regions. This subwatershed was selected as our study area because it has a diverse mix of land-uses ranging from agriculture and urban development, to oil and gas extraction and refining (Fig. 1a). As a result, this subwatershed is considered to be representative of the range of anthropogenic pressures and land-use conflicts that influence wetland loss throughout the province. Land tenure includes a mix of private, provincial, and federal ownership, and approximately 13 % of the watershed has been designated a conservation or protected area. The City of Edmonton, which is the second largest municipality in Alberta, is partially contained within the subwatershed, and covers approximately 0.2 % of the study area. Compared to other regions in southern Alberta, the Beaverhill subwatershed has not experienced the same rate of extreme wetland loss that is generally attributed to the agrarian colonization that occurred in Alberta between the 1890s and the 1930s.

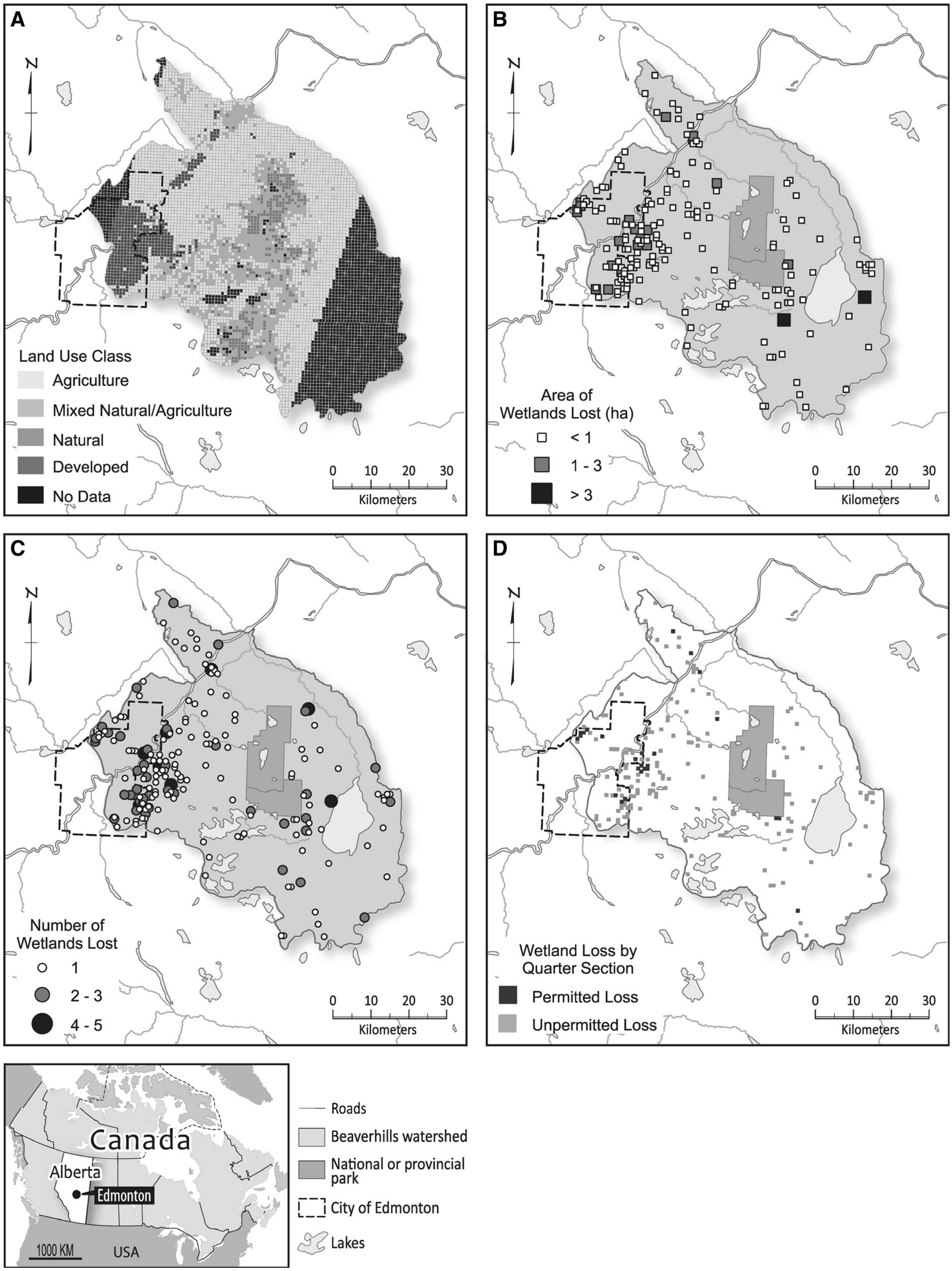
Methods

Wetland inventories

In order to quantify anthropogenic loss of wetlands between 1999 and 2009, we created a wetland inventory for both years using remote sensing techniques. To create the 2009 inventory, an automated hierarchical object-based classification process was developed using data models generated from 3-m light detection and ranging (LiDAR) digital elevation data that was collected in 2009 (average vertical accuracy ~30 cm). A full feature digital surface model (DSM) was generated from first returns and a bare earth digital terrain model (DTM) was generated by subtracting the last returns from the first returns, and applying algorithms to remove probable above-ground features. A probability of depression map was generated by adding random errors to the DTM and calculating the number of times a cell in the DTM was filled using depression filling procedures (Lindsay et al. 2004). The depression probability map was segmented into objects using a multi-resolution segmentation region-merging algorithm (Baatz and Schape 2000), in which each pixel was initialized as an individual "object" and the algorithm "grows" the object by merging it with neighbouring objects with similar values, until a heterogeneity threshold is reached. A vector road layer was used to constrain segmentation to prevent potential wetland objects from crossing roads. The resulting objects were classified as wetlands if the mean depression probability value was >50 %, or if the mean depression probability value was >30 % and mean slope and mean height (calculated by subtracting the DTM from the DSM) were low. To create the 1999 inventory, a manual object-based classification process was applied to 3-m colour aerial photographs from 1999, as digital elevation data were not available for this year.

Wetland inventories from 1999 and 2009 were created using different data and techniques. The lack of elevation data for 1999 meant that fewer wetlands were identified in 1999 as compared to 2009, *particularly dry or shallow wetlands*. To correct for this, we overlaid the 2009 inventory on the 1999 inventory to create an 'enhanced' 1999 inventory, applying the assumption that if a wetland existed in 2009, it also existed in 1999, even if it was not detected.

As the goal of our analysis was to highlight anthropogenic loss, which is identified by wetland area loss, the influence of antecedent meteorological conditions on wetland area needed to be removed. Meteorological data from five weather stations (Edmonton Municipal CR10, Edmonton NMAO, Elk Island National Park, Fort Saskatchewan, and Tofield North) were downloaded from the National Climate Data and Information Archive (Environment Canada 2013) and average precipitation (P) and temperature (T) values for 1998 water year, 1999 growing season, 2008 water year, and 2009 growing season were calculated. Potential evapotranspiration (PET) was


A
Land Use Class
Agriculture
Mixed Natural/Agriculture
Natural
Developed
No Data
0 10 20 30
Kilometers
B
Area of Wetlands Lost (ha)
< 1
1 - 3
> 3
C
Number of Wetlands Lost
1
2 - 3
4 - 5
D
Wetland Loss by Quarter Section
Permitted Loss
Unpermitted Loss
Canada
Alberta
Edmonton
1000 KM
USA
Roads
Beaverhills watershed
National or provincial park
City of Edmonton
Lakes

◀**Fig. 1** **a** SPOT-derived land use by quarter section; **b** wetland area and **c** number of wetlands lost by quarter section; **d** correspondence between quarter sections where detected wetland loss was permitted versus unpermitted in the Beaverhill subwatershed between 1999 and 2009

calculated using the Hamon (1963) method. The 30-year (1981–2010) average was calculated from Edmonton International Airport data, as it was the most complete dataset for this time period.

This analysis showed that 2009 was a much drier than 1999, with PET exceeding precipitation in both the water year (October 2008 to September 2009) and growing season (May to September), meaning there was less open water on the landscape in 2009. Thus, wetland area from 2009 was calibrated to the area of the same wetlands in the 'enhanced' 1999 inventory. Wetlands that existed in both the 'enhanced' 1999 inventory and the original 1999 inventory were identified and were intersected with wetlands from the 2009 inventory, and wetland area for 2009 was calculated. Regression analysis was performed on wetland areas using the area in the 2009 inventory as the independent variable (x) and the area in the intersection between the original and 'enhanced' 1999 inventory as the dependent variable (y). The regression equation was applied to the area values of the 2009 inventory to estimate a 'calibrated' 2009 inventory with climate differences removed. The regression was also applied to wetlands in the 'enhanced' 1999 inventory that did not intersect the original 1999 inventory (i.e., wetlands added from the 2009 inventory that were not identified in the original 1999 inventory).

Calculating wetland loss

The study area was divided into 6,984 quarter sections (a quarter section being 800 m^2) using the Alberta Township Survey grid (Government of Alberta, 2005). Each wetland feature in the 'calibrated' 2009 and 'enhanced' 1999 inventory was assigned to a quarter section. If a wetland feature intersected two or more quarter sections, the wetland was assigned to the quarter section that contained the largest area of wetland. The difference in wetland area between the 'enhanced' 1999 inventory and the 'calibrated' 2009 inventory was quantified by quarter section to create a 'wetland loss inventory'. Given that the 2009 inventory was calibrated to remove the effect of climate, we have made the assumption that any detected loss is the result of anthropogenic activity. As there is no automated technique that can be used to remotely distinguish between drained (as a result of agricultural practices) and dried wetlands, it is likely that we underestimated wetland loss due to drainage.

In order to compare wetland loss and land use, we created a land use map by quarter section using supervised classification of 10-m multispectral SPOT images acquired in 2009. The multispectral images were pan-sharpened to 5-m resolution using 5-m panchromatic SPOT images. SPOT coverage of the study area was incomplete; thus, land use could only be assigned to a portion of the study area (Fig. 1a). Land cover classes were simplified into four categories: 'developed' (i.e., urban, suburban, industrial); 'agriculture'; 'mixed natural/agriculture'; and 'pristine natural'. Land use categories were assigned to quarter sections by majority cover, except for the 'pristine natural' class, which required ≥90 % coverage in a quarter section. Quarter sections with <90 % 'pristine natural' cover were considered'mixed natural-agriculture'. Quarter sections not covered by the SPOT land use map were classified as 'no data'.

This approach to generalizing land use allowed us to better account for land cover at extents that are meaningful to a diversity of wetland flora and fauna (Rooney et al. 2012). For example, a wetland that falls in a wooded lot within a primarily agricultural landscape would normally be assigned a 'natural' designation, but assigning land use by quarter section takes into account land use at a larger spatial scale. It is important to note, however, that we used only a single land use map from 2009; thus, we are not able to attribute wetland loss to land cover changes (e.g. rural to urban) or land "intensification" (e.g., urban to urban, with loss related to a change in policy or planning) over time.

Wetland loss inventory accuracy assessment

The automated wetland loss inventory was checked for errors of omission or commission by manually examining each quarter section in which a wetland loss was detected. Errors of omission were those where a wetland was not identified, despite its existence, while errors of commission identified a wetland in a location when no wetland existed. We also manually checked all quarter sections for which

Table 1 Automated wetland inventory results compared to results from the manually corrected wetland inventory, and calculation of unpermitted wetland loss using the manually corrected inventory in the Beaverhill subwatershed between 1999 and 2009

	Automated wetland loss inventory	Manually Corrected wetland inventory	Permitted loss	Unpermitted loss	Unpermitted loss[a] (%)
Wetland area (ha)	243	71	13	58	82
Number of wetlands	793	242	37	205	85
Quarter sections with impacts	642	179	25	154	86

[a] Unpermitted loss percentages are calculated using data from the manually corrected wetland inventory

we had a *Water Act* approval, as these locations should have corresponded with a permitted loss of wetland area.

Permitted versus unpermitted drainage and wetland permit information tracking

Wetland permit and compensation data was gathered from three different sources: Department of Environment's provincial *Water Act* approvals database; Department of Environment Northern Region Office *Water Act* approval files; and annual wetland compensation reports submitted to the government by the provincial Wetland Restoration Agency. All data were combined together to create a comprehensive list of wetland loss and compensation sites in the Beaverhill subwatershed between 1999 and 2009.

For each approval issued, we gathered the following information: approval number; authorization and expiry date; proponent name; impact and compensation site location; number, class, and size of wetland(s) impacted; type of compensation required [e.g., on-site restoration/construction, off-site restoration/construction, in-lieu fee (ILF) payment]; price paid per hectare (i.e., if a compensation payment was made); and number, class (following Stewart and Kantrud 1971), and size of wetlands created as compensation. In many cases, the desired information was not contained within the files. For example, location data for compensatory wetlands was often missing, particularly in instances where compensation took the form of ILF payments. In addition, data related to the number and class of wetlands impacted, and subsequently created, was often absent from the files.

We quantified permitted versus unpermitted wetland loss by overlaying the wetland loss inventory with quarter section locations where permits were issued by the government between 1999 and 2009; if a wetland loss was detected, we could then determine if the wetland loss was government authorized.

Results

Wetland loss

We expected the following scenarios when tracking wetland loss between 1999 and 2009 in the study area: (a) no change (i.e., wetland present in both 1999 and 2009); (b) change due to wetland removal (i.e., land development); or (c) change due to climatic conditions and/or drainage activity. Using our automated object-oriented wetland loss inventory technique, we could not differentiate between drainage loss (i.e., related to agricultural practices) and climate loss. Thus, in the context of this analysis, drainage and climate loss were not considered "anthropogenic loss", as this category included only those wetlands that were completely removed (i.e., complete loss of open water and/or wetland basin).

The total area of wetlands in the study area in 2009 was estimated to be 39,130 ha, or ~9 % of the study area. The difference in wetland area between the enhanced 1999 inventory and the 2009 climate calibrated inventory was 243 ha, representing the loss of 793 wetlands in 642 quarter sections (Table 1). When each quarter section was manually checked to confirm loss, we found that the automated wetland inventory overestimated the area of wetland loss by 172 ha (71 %). This overestimate of loss was attributed to errors of commission associated with the 1999 inventory (276 wetlands totaling 58 ha) and errors of omission associated with the 2009 inventory (273 wetlands totaling 114 ha). Errors of commission in the 1999 inventory included misclassification of shadows and forest as wetlands. Errors of omission in the 2009 inventory included the exclusion of dry, shallow wetlands that failed to meet the automatic classification criteria of high mean depression probability, low mean slope, and low mean height. Other omission errors included the exclusion of wetlands located next to tall objects, such as trees, the automatic removal of wetlands that were within 20 m of a roadside ditch, and wetlands that did not meet the depression probability value of $\geq$0.3, and were thus removed in the first step of the wetland inventory classification process.

When the automated wetland loss inventory was corrected for errors, the total area of anthropogenic loss between 1999 and 2009 was calculated to be 71 ha, totaling 242 wetlands in 179 quarter sections (Table 1, Fig. 1b, c). This loss represented complete removal of wetlands and did not include loss due to drainage activities (i.e., water was drained, but the wetland basin remains). As a result, it is highly likely that we have underestimated anthropogenic loss of wetlands in the study area.

The proportion of wetland area loss between 1999 and 2009 was greatest in quarter sections categorized as 'developed' and 'agriculture'. A total of 37 % of wetland area losses occurred in 'developed' areas, which represented only 7 % of the study area, whereas 39 % of wetland area losses occurred in 'agricultural' areas that represented 48 % of the study area. A further 20 % of wetland loss occurred in quarter sections without SPOT land use map coverage, which covered 25 % of all study area; thus, we could not characterize wetland loss by land use in these areas. Wetland loss was lowest in quarter sections characterized as 'mixed natural/agricultural' (4 % loss and 16 % of study area) and 'pristine natural' (0.1 % loss and 4 % of study area). These results suggest that wetland loss in the Beaverhill subwatershed is greatest in areas where land use is dominated by urban, peri-urban, and industrial development, such as in the City of Edmonton, which accounted for over half (4.4 %) of the total 'developed' area loss. It should be noted, however, that our inability to detect agricultural drainage as 'anthropogenic loss' may confound this result.

Permitted versus unpermitted drainage

In total, we documented 66 *Water Act* approvals issued for wetland impacts in the Beaverhill subwatershed between 1999 and 2009. These approvals authorized wetland impacts in 141 quarter sections, for an average of 2.1 quarter sections per approval. It was not unusual for the government to authorize wetland impacts over large areas. For example, 12 % of approvals authorized impacts in $\geq$5 quarter sections, and one approval authorized wetland impacts in 32 quarter sections. Approvals authorizing impacts over large areas were typically associated with residential developments or major infrastructure projects, such as roads.

When we manually compared quarter sections where wetland loss was detected by the automated inventory, to quarter sections where we had *Water Act* documentation of a loss, we found a 28 % correspondence between detected and documented loss. In 36 % of cases, we found that a permit had been issued for wetland loss, but there was no visual evidence of wetland loss at that same location between 1999 and 2009. In 4 % of cases, our wetland inventory underreported permitted wetland loss, either because the loss was partial, or because the wetland was replaced on-site, and thus, our inventory did not detect a loss. In 33 % of cases, a permit had been issued for loss, but our inventory did not detect the loss due to an error of commission (1 %) or omission (32 %). Omission errors were due largely to the low quality of the 1999 imagery and lack of high resolution digital elevation data, which made it very difficult to identify small, ephemeral or seasonal wetlands (i.e., Class I, II, and III; Stewart and Kantrud 1971) in the 1999 image. These results suggest that the automated wetland inventory likely underestimated the number and area of ephemeral, seasonal, and temporary wetlands in the study area.

When the manually corrected wetland inventory was overlaid on those quarter sections with a *Water Act* approval, we found that only 14 % of the lost wetlands fell within a quarter section with a corresponding approval (Fig. 1d). The permitted losses accounted for only 13 ha of the lost wetland area, which suggests that over 80 % of the wetland area that was lost between 1999 and 2009 occurred without a government permit (Table 1).

Information tracking

When we examined details of the 66 wetland approvals that were issued in the Beaverhill subwatershed between 1999 and 2009, we found serious issues related to information tracking.

For example, the government requires compensation when wetland impacts cannot be avoided or minimized; however, in 21 % of the approvals we examined ($n = 66$), there was insufficient information available on-file to determine the kind of compensation (if any) required by the government. ILF payments made up the biggest proportion of compensation ($n = 22$), but only 32 % of permits that required an ILF payment were tracked by all three agencies responsible for regulating and administering wetland compensation (Table 2). Six approvals appeared in government records without a corresponding approval appearing in the annual reports of the provincial Wetland Restoration Agency, which amounted to compensatory payments of just under $131,240. On the other hand, the provincial Wetland Restoration Agency had records indicating that they had received ILF payments for five approvals, amounting to over $77,000, for which there was no corresponding government record of an approval having been issued. Such inconsistencies lead to a lack of transparency and undermine the credibility of, and public confidence in, both the wetland restoration agent and the government to adequately implement the wetland policy.

For the other approvals that did not require an ILF payment ($n = 44$), the tracking of permits between provincial sources appears to be similarly lax. Only 25 % of approvals appeared in data provided by both the regional office and the provincial *Water Act* database. This means that for 75 % the approvals we examined, relevant information regarding wetland impacts and compensation could be found in only one of the two government sources we accessed for this analysis.

Table 2 In-lieu fee payment recorded in the provincial government database (Provincial), by the regional government office (Regional), and by the provincial wetland restoration agent (WRA) in the Beaverhill subwatershed between 1999 and 2009

Source	Number of approvals	Percentage of approvals tracked	ILF payment (2009$)
Provincial/ Regional/WRA	7	32	$207,821.00
Provincial/ Regional	6	27	$131,239.48
Regional/WRA	2	9	$264,548.73
Provincial/WRA	2	9	$4,753.91
WRA	5	23	$77,232.20
TOTAL	22	100	$685,595.32

Ideally, we would have liked to compare the area and number of wetlands lost in each quarter section, as measured by our wetland loss inventory, to the number and area of wetlands authorized for loss in each *Water Act* approval. Given the stated goals of the wetland policy, it seems reasonable to expect that the government would specifically track the area and number of wetlands authorized for loss by quarter section, such that they could track these metrics over time. We were not able to directly compare calculated wetland loss to authorized wetland loss because nearly one quarter (22 %) of the approvals we examined lacked information about the area and/or number of wetlands that were authorized for loss by the government.

Discussion

Natural resource policies should be designed with quantifiable metrics of success, if the objective of those policies is to facilitate reflexive and adaptive management of natural resources. At the core of any evidence-based policy analysis is access to precise and accurate data, and government agencies must have the policy analytic capacity to develop and measure metrics that allow for the evaluation of policy success over time. In this study, we highlighted the need for the Government of Alberta to improve policy analytic capacity in the area of wetland management, by evaluating three metrics of policy success: (1) no net change of wetland area; (2) permitted versus unpermitted wetland loss; and (3) an information tracking system that provides credible regulatory oversight.

One of the most significant technical challenges we faced in conducting this study was a lack of current or historical wetland inventory data for the province of Alberta; thus, in order to track wetland loss over time, we first had to develop a wetland loss inventory. This highlights one of the most significant limitations to effective wetland management in Alberta, as well as many other jurisdictions: the availability of credible and accurate inventory data that is freely and publically available. While the spatially and temporally dynamic nature of wetlands makes them challenging to identify, recent advances in automated remote sensing techniques hold much promise for overcoming this challenge, especially as remote sensing data becomes available at finer spatial and temporal scales (Creed and Sass 2011; Sass and Creed 2011), innovative wetland mapping techniques are developed (e.g., Clark et al. 2009; Kaheil and Creed 2009; Halabisky and Moskal 2011), and geographical information systems and remote sensing image processing techniques become simplified and accessible for general use (e.g., Whitebox geospatial analysis tools, an open source GIS and remote sensing package developed by J.B. Lindsay, University of Guelph).

While the future looks promising from the perspective of generating the technical expertise and data needed to map wetlands and to track their loss over time, governments must also deal with challenges associated with the governance of these important wetland ecosystems. The results from this study suggest that over 80 % of the wetland area losses occurred without government permits, highlighting an important governance issue around public compliance and government enforcement of existing wetland regulation. While issues of wetland compliance and enforcement are not unique to the province of Alberta (Clare et al. 2011), the lack of information available regarding the type of non-compliance, as well as the individuals or organizations most likely to be in non-compliance, severely limits an effective government response to this issue.

The need for reliable data extends to the decision-making process itself, including the way in which the government handles and tracks information and data that both informs, and results from, wetland permit decisions. We found that permit information was fragmented among government offices, and between the government and non-government agencies that are responsible for wetland regulatory and policy oversight. Often, this information is only available in analog format in government offices, and key pieces of information are missing or difficult to find, making it effectively inaccessible for use in policy evaluation. Under such conditions of inaccessible and insufficient information, there is little opportunity for regulators to learn from the outcomes of previous decisions, and it is difficult for the public to scrutinize such decisions, which can ultimately lead to outcomes that favor the interests of the regulated industry over the public interest (Clare and Krogman 2013; Clare et al. 2013).

Recommendations and opportunities

For natural resource policy to meet stated goals and objectives, governments and other agencies responsible for policy oversight must have the analytic capacity to measure the natural resources they have been tasked with managing. Governments are increasingly being called upon to design and implement effective natural resource policies in the midst of exceptionally challenging social and economic conditions, often with decreasing financial resources for those agencies or departments that have been charged with such tasks. The result has been sub-optimal policy outcomes that are driven by short-term ‘crisis’ decision making, and a divestment of resources away from activities that build analytic policy capacity over the medium- and long-term (Howlett and Joshi-Koop 2011). Given that budgetary challenges are unlikely to diminish in the near-term, governments must begin to make more strategic decisions about how, and where, to spend public dollars. Investing in the acquisition of fine resolution spatial data (e.g., LiDAR and air photos), and making these data publically available, is an important first step in developing the policy capacity to measure and monitor wetland change over time. Most importantly, governments must begin to calculate the costs associated with policy inaction (e.g., loss and damage due to flooding, water quality treatment), and more research efforts need to be directed towards understanding the true economic, social, and environmental costs of wetland loss.

This study clearly highlights the challenges associated with tracking wetland policy outcomes over long time periods and at broad spatial scales. These challenges are not easily overcome without a strong a commitment to provide the financial resources needed to create the information required to enhance government decision-making and public oversight. We feel that the advancements in data acquisition and management systems that have benefitted many other fields, from finance to geomatics, need to “infiltrate” into natural resource management activities (Pardo et al. 2010), with the goal of creating networked and IT-enabled public administration, particularly in departments that regularly mange common pool resources, such as wetlands. While we intuitively feel that improving information about wetlands and increasing access to this information for government decision-makers and the public will improve policy outcomes, there is a paucity of academic literature in this area of study, and therefore, we feel there is a need for more evaluative research that examines how improvements in the creation and delivery of policy-relevant information improves policy outcomes.

Investing in the generation of meaningful information and making this information freely available and readily accessible will create conditions for increased participation in natural resources management by different actors across a spectrum of interests. The 'opening up' of wetland management and decision making to include active participation from informal institutions, local governments, and the general public may serve to improve regulatory oversight and wetland policy outcomes (Lockwood et al. 2010). In addition, making wetland inventory information available through web-based mapping applications may engage and empower social actors who are marginalized from more traditional, formal government decision-making processes (Wright et al. 2009). By increasing the policy-analytic capacity of government, and producing information that can be used by a broad range of policy actors, the decision-making process and the outcomes of those decisions will be much more transparent. Ultimately, it is our hope that this increased transparency will lead to improved outcomes for wetland habitats worldwide.

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