On the importance of ground validation and methodology for wetland mapping in Canada

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Abstract

In this study, existing national wetland maps were compared with ground truth sites used to map wetlands in four areas of interest (AOIs) located in Eastern Canada . By comparing methods used for each map, we identified the following important elements to consider when mapping wetland using remotely sensed data: 1) the five Canadian Wetland Classification System (CWCS) classes (bog, fen, swamp, marsh, shallow water) are broad and can create spectral confusion (it is preferable to use wetland subclasses and then merge them into the broad classes); 2) it is important to add SAR imagery to the classification, given that the radar imagery can detect many wetland characteristics related to the site wetness and vegetation structure. 3) ancillary data, such as DEM, topographic metrics, are a valuable addition to the classification; 4) it is recommended to use multi-seasonal images to consider the temporal variation in the vegetation phenology and in both surface and groundwater levels (both are critical elements for delineating wetlands and periodically flooded areas); 5) images used should have a spatial resolution small enough to have a minimum mapping unit low enough to be able to detect small landscape features; and 6) it is recommended to have a dense network of ground-truth sites representative of the AOI. This study showed that mapping wetlands at the scale of Canada is very challenging, due in part to the diversity of wetland types, which complicates the definition of standardised wetland classes, as well as to the logistical challenges in obtaining data.

1. Introduction

Wetlands are complex ecological systems formed when hydrological and geomorphological conditions lead to prolonged soil saturation, allowing hydrophytic and water-tolerant plants to grow (Warner and Rubec, 1997; Rubec, 2018). Given that wetlands are facing numerous pressures from human activities, invasive species, and climate change, appropriate databases can be used directly to monitor biodiversity, inform conservation efforts, and guide climate change mitigation and adaptation strategies.

As in other countries, wetlands in Canada are essential because they protect against floods and droughts, act as natural water filters, support diverse wildlife habitats, and store large amounts of carbon, thereby helping to mitigate climate change. They also hold significant cultural value for many Canadian communities, particularly Indigenous peoples, due to their role in resource collection. Mapping wetlands for a vast country like Canada is challenging. Still, it is needed because such a map can be used to monitor biodiversity conservation and guide climate change mitigation and adaptation strategies.

In the past, many remote sensing studies on wetland mapping were published in Canada. Two Canadian-wide wetland maps recently produced exist. The first one is the Canadian Wetland Inventory Map (CWIM), published by Natural Resources Canada (NRCan, 2004). It corresponds to the high-resolution 10-m wetland map generated for each ecozone, as defined by *Wiken et al.* (1996), from multi-year (2016-2020), multi-source optical and Synthetic Aperture Radar (SAR) satellite imagery, as well as some environmental features, following the method described in Mahdianpari *et al.* (2021). The resulting map only displays the five major wetland classes defined in the Canadian Wetland Classification System (CWCS), as described in Warner and Rubec (1997) and Rubec (2018). The last version of the map (3A) can be downloaded from the Open Canada website (NRCan, 2024).

The second wetland national map correspond to the geodatabase developed by the Canadian National Wetland Inventory (CNWI) database, developed and standardized by the Canadian Wildlife Service (CWS) of Environment and Climate Change Canada (ECCC 2025). This database includes wetland polygons gathered from federal, provincial, and territorial governments, academia, Indigenous groups, and non-governmental organizations (NGOs). In addition to the five major wetland classes, the CNWI database also included eight subclasses (Rich Fen, Poor Fen, Organic Swamp, Mineral Swamp, Organic Marsh, Mineral Marsh, Shallow Water, and Open Water). Details about the method for wetland mapping included in the CNWI database were published for the Province of Ontario (OMNRF, 2014), Québec (Leboeuf *et al.*, 2012), and New Brunswick (Colpitts, 2017).

Still, none of these studies listed the key elements to consider when mapping wetlands using remotely sensed data. This paper describes these key elements that were determined by comparing the methodology used to produce several existing wetland maps in four areas of interest (AOI) located in Eastern Canada (Figure 1) and having contrasting land covers: 1) a part of the Hudson Bay Lowlands in northern Ontario (ON); 2) the coastal zone of Eeyou Itschee James Bay (QC); 3) southern New Brunswick (NB) and 4) the region of Halifax in Nova Scotia (NS). Given the diversity of wetland types in these four AOIs, they provide excellent case studies for determining the key elements for mapping wetlands from remotely sensed data. While the paper does not propose new methodologies for wetland mapping with remote sensing, it is the first time that a comprehensive and detailed analysis of wetland map accuracies is presented across a variety of landscapes, which uses a substantial amount of ground-truth data not used in the image classification step.

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Figure 1. Location of the four areas of interest (AOIs).

2. Study areas

This study uses data acquired on four AOIs located in eastern Canada (Figure 1). The northern Ontario AOI (ON) is found in the southern part of the Hudson Plains Ecozone, characterised by extensive peatlands (Figure 1). The area has a topography that ranges from 27 m above mean sea level (AMSL) (close to the Hudson Bay) to 174 m AMSL (in the southwest corner). Like most of the Hudson Plains Ecozone, the area is dominated by extensive wetlands, mostly peatlands (Ou *et al.*, 2016). It is located near the southern limit of discontinuous permafrost.

The Eeyou Itschee AOI (QC) is part of the traditional territory of the Cree Nation, and runs along the eastern coastline of James Bay, in western Québec (Figure 1). It is primarily located within the Taiga Shield Ecozone, spanning part of Canada's subarctic zone. It has a diverse and often rugged landscape that includes boreal forests, tundra, wetlands, rivers, and lakes. The boreal forest dominates the area, but this region also contains numerous wetlands, including bogs, swamps, and fens, which are essential for wildlife.

The Southern New Brunswick AOI (NB) extends from the centre of the province of New Brunswick to the Bay of Fundy coast (Figure 1). It is located within the Atlantic Maritime Ecozone, which encompasses a coastal marine environment. This AOI is dominated by the extensive floodplains of the Saint John River and its tributaries. Its elevation ranges from 0 m to 470 m AMSL in the highest part of the study area. The Southern New Brunswick AOI is a priority wetland conservation area for the Eastern Habitat Joint Venture and has a high number of easily accessible wetland sites for ground-truthing (LaRocque *et al.*, 2020). While most of the study area still has natural landscapes, it faces increased pressure from expanding agriculture and urban developments.

Finally, the Halifax (NS) AOI is located at the mouth of a large bay, along the Atlantic coastline (Figure 1). It is also located in the Atlantic Maritime Ecozone. Its elevation ranges from 0 m AMSL along the Halifax Harbour to 150 m AMSL on the northwest edge of the study area. Although significant zones are experiencing increased pressure from urban development, most of this AOI still has natural forested landscapes (Jahncke *et al.*, 2018). Its poorly drained soils provide suitable conditions for wetland development.

3. Materials and Methods

To determine best practices for mapping wetlands using remotely sensed data, we analysed the methodologies used to produce the existing wetland maps in each AOI, with accuracy assessed by comparing each map to ground-truth sites visited during fieldwork (Table 1).

Class	ON	QC	NB	NS
Bog	494	67	99	47
Fen	135	124	63	40
Marsh	-	131	82	16
Swamp	-	43	197	58
Shallow Water	41	67	64	21
Wetlands	670	432	505	182
Non wetland	178	656	446	128
Total	848	1088	951	310

Table 1. Number of ground-truth sites used for assessing the existing wetland maps in each AOI.

The original polygon for each wetland site exhibited a high diversity of wetland classes; however, they were grouped into five major wetland classes (Bog, Fen, Marsh, Swamp, and Shallow Water), as defined by the Canadian Wetland Classification System (CWCS) (Rubec, 2018). The comparison among maps considered only these five classes. The input data and classifier used for each map are presented in Table 2 for the ON AOI, Table 3 for the QC AOI, Table 4 for the NB AOI, and Table 5 for the NS AOI.

Inputs	Ou et al. (2016)	NRCAN (2024)	ECCC (2025)
Optical Images	Landsat-5 TM	Sentinel-2	IKONOS, IRS, Landsat MSS, TM, ETM+
SAR images	Radarsat-2 (C-HH, C-HV)	Sentinel-1 (C-HH, C-HV, C-VH, C-VV) Alos-PalSAR 2 (L-HH, L-HV)	None
Topography metrics	Canadian DEM (elevation)	SRTM or Arctic DEM (elevation, slope, aspect)	None
Other data	None	Temperature, precipitation, nighttime lights	None
Seasonal effect	3 images/year	1 image/year	1 image
Classifier	Random Forests	Random Forests	Airphoto interpretation
# wetland classes	9	5	3

Table 2. Methodology used for each of the existing maps of the ON AOI

Inputs	LaRocque *et al.* (2024)	NRCAN (2024)	ECCC (2025)
Optical Images	Landsat-8 OLI	Sentinel-2	RapidEye, Spot, Landsat-TM
SAR images	Sentinel-1 (C-HH, C-HV, C-VH, C-VV)	Sentinel-1 (C-HH, C-HV, C-VH, C-VV) Alos-PalSAR 2 (L-HH, L-HV)	None
Topography metrics	SRTM DEM (elevation, slope)	SRTM or Arctic DEM (elevation, slope, aspect)	None
Other data	None	Temperature, precipitation, nighttime lights	None
Seasonal effect	3 images/year	1 image/year	1 image
Classifier	Random Forests	Random Forests	Airphoto interpretation
# wetland classes	11	5	5

Table 3. Methodology used for each of the existing maps of the QC AOI

Inputs	LaRocque *et al.* (2020)	NRCAN (2024)	ECCC (2025)
Optical Images	Landsat-8 OLI	Sentinel-2	Aerial photographs
SAR images	Sentinel-1 (C-HH, C-HV, C-VH, C-VV) Alos-PalSAR 1 (L-HH, L-HV)	Sentinel-1 (C-HH, C-HV, C-VH, C-VV) Alos-PalSAR 2 (L-HH, L-HV)	None
Topography metrics	LiDAR DEM (elevation, slope, curvature, TPI*, TWI*)	SRTM or Arctic DEM (elevation, slope, aspect)	None
Other data	LiDAR CHM*	Temperature, precipitation, nighttime lights	LiDAR
Seasonal effect	3 images/year	1 image/year	1 image
Classifier	Random Forests	Random Forests	Airphoto interpretation
# wetland classes	11	5	6

Table 4. Methodology used for each of the existing maps of the NB AOI (*TPI: Topographic Position Index; TWI: Topographic Wetness Index; CHM: Canopy High Model)

Inputs	Jahncke et al. (2018)	NRCAN (2024)	ECCC (2025)
Optical Images	Quickbird	Sentinel-2	Aerial photograph, Landsat-ETM+
SAR images	Radarsat-2 C-band SLC polarimetric images	Sentinel-1 (C-HH, C-HV, C-VH, C-VV) Alos-PalSAR 2 (L-HH, L-HV)	None
Topography metrics	LiDAR DEM (elevation, slope, curvature, CTI*, TPI*)	SRTM or Arctic DEM (elevation, slope, aspect)	None
Other data	LiDAR CHM*	Temperature, precipitation, nighttime lights	None
Seasonal effect	4 images/year	1 image/year	1 image
Classifier	Random Forests	Random Forests	Airphoto interpretation
# wetland classes	6	5	7

Table 5. Methodology used for each of the existing maps of the NS AOI (*TPI: Topographic Position Index; TWI: Topographic Wetness Index; CHM: Canopy High Model)

4. Results and Discussion

4.1 Mapping accuracy

Table 6 compares the accuracies of the existing maps for each AOI. The most accurate maps are those of Ou *et al.* (2016) for the ON AOI, LaRocque *et al.* (2024) for the QC AOI, LaRocque *et al.* (2020) for the NB AOI, and Jahncke *et al.* (2018) for the NS AOI. The NRCAN (2024) map is noticeably more accurate than the ECCC (2025) map in the NS AOI, but the opposite is true for the QC AOI.

AOI	Number of ground-truth polygons	Mapping Accuracy (%)		
		Regional studies*	NRCAN 2024	ECCC 2025
ON	848	97.8	56.3	54.1
QC	1088	96.5	49.6	59.7
NB	951	98.9	63.4	66.5
NS	310	92.9	55.2	47.7

Table 6. Mapping accuracy (%) of the existing maps for each AOI

*Ou *et al.* (2016) for the ON AOI; LaRocque *et al.* (2024) for the QC AOI; LaRocque *et al.* (2020) for the NB AOI; and Jahncke *et al.* (2018) for the NS AOI.

The wetland areas by class for each existing map are provided in Table 7 for the ON AOI, Table 8 for the QC AOI, Table 9 for the NB AOI, and Table 10 for the NS AOI. The largest total wetland area was associated with the regional studies for the QC, NB, and NS AOIs. In contrast, the NRCAN (2024) map showed the largest total wetland area in the ON AOI. The ECCC (2025) map gives the smallest wetland area in each AOI. The largest difference in wetland area across the various maps occurs in the NB and NS AOIs.

Class	Ou *et al.* (2016) (km^2)	NRCAN (2024) (km^2)	ECCC (2025) (km^2)
Bog	3533.7	4108.5	3178.4
Fen	871.5	2716.0	3195.9
Swamp	-	286.0	575.9
Shallow water	11.2	231.9	-
Total	5336.8	7342.4	6950.2

Table 7. Wetlands area in the ON AOI.

Class	LaRocque *et al.* (2024) (km^2)	NRCAN (2024) (km^2)	ECCC (2025) (km^2)
Bog	3567.0	2296.6	5143.7
Fen	2368.3	2565.7	685.1
Marsh	580.4	1150.7	83.3
Swamp	192.5	255.2	641.8
Shallow water	728.7	699.1	-
Total	7436.8	6967.3	6553.9

Table 8. Wetlands area in the QC AOI.

Classes	LaRocque *et al.* (2020) (km^2)	NRCAN (2024) (km^2)	ECCC (2025) (km^2)
Bog	2630.0	95.1	218.1
Fen	353.0	741.8	216.7
Marsh	184.0	488.4	256.2
Swamp	1248.0	360.1	1477.6
Shallow water	951.0	940.4	55.5
Total	5366.0	2625.8	2224.1

Table 9. Wetlands area in the NB AOI.

Classes	Jahncke *et al.* (2018) (ha)	NRCAN (2024) (ha)	ECCC (2025) (ha)
Bog	286.7	7.6	14.2
Fen	123.1	197.9	47.1
Marsh	113.9	68.7	162.5
Swamp	650.2	12.8	23.3
Shallow water	283.5	450.9	2.3
Total	1457.4	738.0	249.4

Table 10. Wetland areas in the NS AOI.

4.2 Considerations when mapping wetlands

Tables 6 to 10 show that the wetland maps of the studied AOIs have variable accuracies. As described in Tables 2 to 5, the methods used to produce each wetland map vary among studies. A comparison of methods should enable us to identify key factors that influence mapping accuracy when mapping wetlands from remotely sensed data.

4.2.1 Number of classes

Except for the NS AOIs (Table 5), the most accurate maps (Ou *et al.*, 2016; LaRocque *et al.*, 2020, 2024) are associated with the highest number of wetland classes (Tables 2-5). Indeed, considering only the five broad CWCS wetland classes could lead to low class spectral separability because these classes have high spectral heterogeneity due to variation in vegetation size and density (open, shrub, or treed) and vegetation type (deciduous vs coniferous). As a result, there can be confusion between treed bogs and coniferous forests, or between broadleaf swamps and hardwood forests. Such a problem is more acute in the NRCAN (2024) map because the "Bog" and "Fen" classes in some ecozones were grouped when the number of wetland sites was deemed to be too low. This was also the case with the NRCAN (2024) map, where all the upland land cover classes were grouped into a single non-wetland class. The use of subclasses such it was done for the map of the regional studies (Ou *et al.*, 2016, Jahncke *et al.*, 2018, and LaRocque *et al.*, 2020, 2024) and ECCC (2025) should be recommended as it allows a better definition of each wetland class by discriminating between the vegetation cover type (tree, shrub, open) and the nature of the soil (organic vs. mineral).

4.2.2 Use of SAR imagery

For all the AOIs, the existing maps were based on optical images. Still, only the maps of NRCAN (2024), Ou *et al.* (2016), Jahncke *et al.* (2018) and LaRocque *et al.* (2020, 2024) were produced by classifying a combination of optical and SAR imagery. Adding SAR imagery should be useful when mapping wetlands, as it can detect many characteristics related to site wetness and vegetation structure (Baghdadi *et al.*, 2001).

4.2.3 Use of ancillary data

For all the AOIs, the existing maps, except the ECCC (2025), used a digital elevation model (DEM) and associated topographic metrics data in the classification. Topographic metrics may include slope, curvature, Topographic Position Index (TPI), and/or Topographic Wetness Index (TWI). These topographic metrics should be considered for wetland mapping, as they are related to terrain morphology, which influences water flow across landscapes and thus plays a major role in defining where wetlands can develop (Millard *et al.*, 2013).

Several studies considered other ancillary data. Jahncke *et al.* (2018) and LaRocque et al. (2020) also considered the Canopy Height Model (CHM), computed by subtracting the DSM (Digital Surface Model) from the DTM (Digital Terrain Model) layers extracted from LiDAR data. CHM offers the advantage of explicitly accounting for vegetation height in the classification. The NRCAN (2024) map was produced by considering temperature, precipitation, and nighttime light data in the methodology. For the ECCC (2025) map of the NB AOI, LiDAR metrics were also considered in the analysis.

4.2.4 Use of multi-seasonal images

In contrast to the most accurate maps (Ou *et al.* 2016, Jahncke *et al.*, 2018, LaRocque *et al.*, 2020, 2024), the less accurate maps were produced using only one annual image per area, acquired mainly during summer (NRCAN, 2024; ECCC; 2025). Such a method did not account for variation in vegetation phenology (leaf-off vs leaf-on) or seasonal differences in the water table level. Both are critical elements for delineating wetlands and periodically flooded areas. Detecting variations in water levels in wetlands reduces confusion among land-cover types with low vegetation, including marshes, fens, and agricultural fields.

4.2.5 Minimum mapping unit

To accurately identify the largest possible number of wetlands, the methodology must allow detection of the smallest features. The spatial resolution of the image defines the Minimum Mapping Unit (MMU), which is the smallest feature that can be detected in the image. The MMU is 0.0075 ha for the maps of LaRocque *et al.* (2020, 2024), 0.015 ha for the map of Ou *et al.* (2016), and 0.032 ha for the map of Jahncke *et al.* (2018). The ECCC (2025) has an MMU ranging from 0.500 ha for the map covering the province of Nova Scotia to 3 ha for the map covering the northern part of the province of Québec. The NRCAN (2024) map was produced with images having a spatial resolution of 10 m. Its theoretical MMU should be 0.01 ha; however, all polygons smaller than 1 ha were removed during processing because they were deemed to lack sufficient spectral information to be useful in the classifier (Mahdianpari *et al.*, 2021). Polygons larger than 100 ha were also removed because they could be spectrally heterogeneous. The resulting MMU for the NRCAN (2024) map is 1 ha.

4.2.6 Representativeness of ground-truth polygons

The most accurate maps, produced by Ou *et al.* (2016), Jahncke *et al.* (2018), and LaRocque *et al.* (2020, 2024), used a dense network of ground-truth sites. The area represented by each polygon ranges from 0.15 km^2 for the NS AOI to 17.80 km^2 for the QC AOI. The NRCAN (2024) map was based on a less dense network of training and testing polygons. As a result, on average, only one polygon used for image classification is found over an area of 407.62 km². Furthermore, this map was created ecozone by ecozone, which significantly influenced the resulting map. As Figure 2 shows, the peatland area of the Hudson Plain ecozone does not extend into the Taiga Shield ecozone, suggesting that the extent of this type of wetland stops at the ecozone boundary. By contrast, the ECCC (2025) map was not produced by classifying images with ground-truth sites but through photo-interpretation.

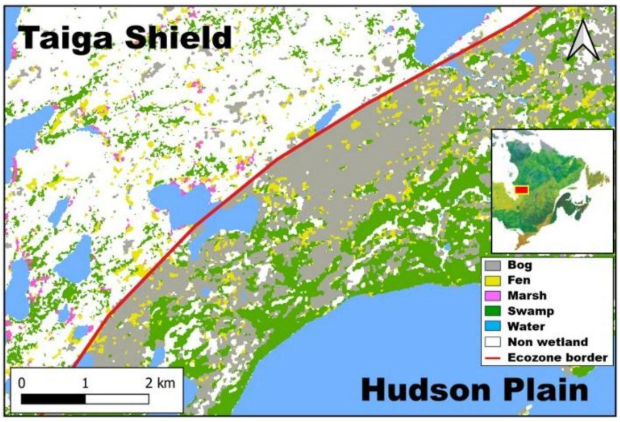

Figure 2. Differences in the wetland type between the two ecozones for the NRCAN (2024) map in the QC AOI.

5. Conclusions

In our study, we provided new quantitative analysis of wetland map accuracy by validating existing wetland maps for four AOIs in Eastern Canada against ground-truth polygons. The most accurate maps were those produced by Ou *et al.* (2016) for the ON AOI, by Jahncke *et al.* (2018) for the NS AOI, by LaRocque

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et al. (2020) for the NB AOI, and by LaRocque *et al*. (2024) for the QC AOI. By comparing the methods used for each map, we identified the following factors that are important to consider when producing a wetland map using remotely sensed data: 1) the five CWCS classes (bog, fen, swamp, marsh, shallow water) are broad and can create spectral confusion. It is preferable to use wetland subclasses and then merge them into the broad classes; 2) SAR imagery is important, given that it can detect many wetland characteristics related to the site's wetness and vegetation structure; 3) Ancillary data such as DEM, topographic metrics, and a canopy height model are valuable additions to the classification; 4) Multi-seasonal images are important because they incorporate seasonal variation in vegetation and water levels. Both are critical elements for delineating wetlands and periodically flooded areas; 5) Images used should have a spatial resolution small enough to have a minimum mapping unit lower than 1 ha to be able to detect the small landscape features; and 6) A dense network of ground-truth sites that are small enough to be representative of the areas they are related to will improve accuracy.

The total wetland area extracted from the map of each regional study was the largest for each AOI, except for the ON AOI, where the NRCAN (2024) map provided the largest area. The maps from ECCC (2025) gave the smallest wetland area in each AOI. The largest difference in wetland area across the various maps occurs in the NB and NS AOIs.

Our study is unique because it is the first to list the key elements to consider when mapping wetlands using remote sensing. It also shows that mapping wetlands at the scale of Canada is very challenging, due in part to the diversity of wetland types, which makes defining standardised wetland classes more complex, as well as to the logistical challenges of obtaining data at the Canadian scale. Wetland mapping remains an important task, as wetland maps can be used in a variety of contexts, ranging from delineating wetland boundaries for regulatory purposes to modelling wetland ecological functions (e.g., carbon sequestration, greenhouse gas emissions, and removals) at a landscape scale.

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