Wetland Inventory System for NL using Satellite Data (What has been Done and What Is the Next Step)

Presented by:

Meisam Amani, PhD

Remote Sensing Engineer, Climate Consulting Group, Met-Ocean Services, Environment & Infrastructure Solutions, Wood

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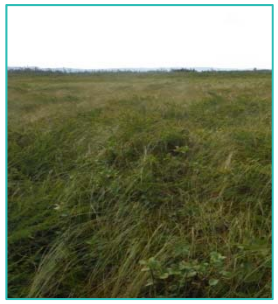
Wetland Service

- Flood control
- Erosion control
- Water purification
- Shoreline protection
- Soil and water conservation
- Carbon storage
- Recreation and tourist activities

Wetlands in NL

Bog

Fen



Marsh

Swamp

Shallow Water

Wetland Classification Methods

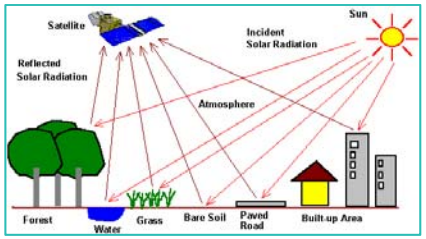
- Traditional (e.g., field work)
  - Expensive
  - Time-consuming
  - Not practical for large areas
  - No practical for wetland change detection and monitoring
  - Accessibility issues
  - **Necessary for remote sensing methods**

- Remote Sensing
  - Cost effective
  - Real-time data
  - Large coverage
  - Repetitive observation
  - No limitation regarding the accessibility

Remote Sensing

- Remote sensing is defined as the measurement of object properties on the earth's surface using data acquired from aircrafts and satellites
- Remote sensing satellites for wetland classification:

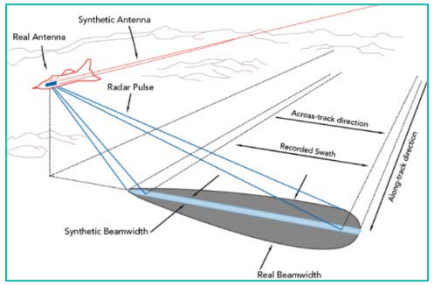
Optical



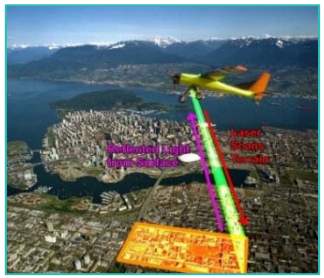
UAV

Hyperspectral

SAR



LiDAR



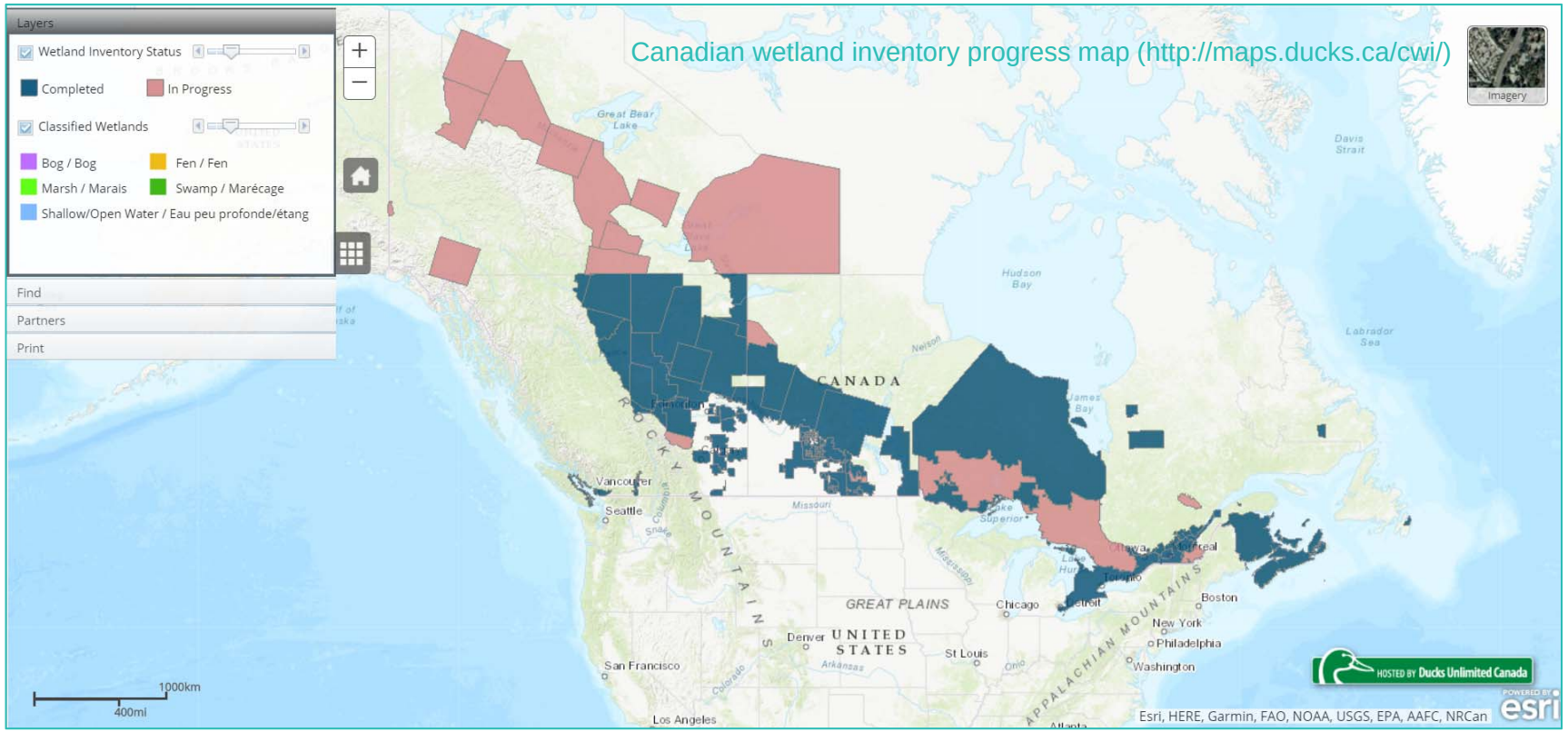
SmallSats

Importance of Wetland Classification in NL

- ~18% of NL is covered by wetlands
- Over the last decades, industrialization, urbanization, and agricultural activities have posed a serious threat to wetlands in the province
- Newfoundland has no comprehensive wetland inventory

Wetland Classification in NL (3 years ago)

- Only two small areas were classified
- Using basic methods
- Some sporadic field works



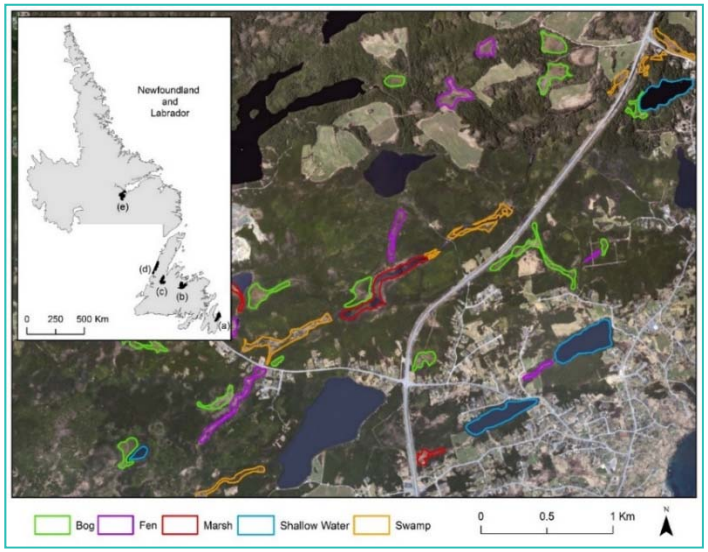
Wetland Classification in NL (up to now)

Study areas

Wetland Classification in NL (up to now)

Field data

- Conducted in summer 2015, 2016, 2017
- Ancillary information, including GPS points, on-site photographs, field notes on dominant vegetation, and hydrology were collected at each wetland site
- The GPS points were inserted into ArcMap and, then, the boundary delineation was conducted using high resolution images
- Based on Canadian Wetland Classification System (CWCS)
- Five wetland classes: Bog, Fen, Marsh, Swamp, and Shallow Water
- Three non-wetland classes: Deep Water, Urban, and Upland



The number of field samples (polygons) collected over five study areas.

Study area	Class	Number of polygons	Area (ha)
Avalon	Bog	83	269
	Fen	39	80
	Marsh	50	62
	Swamp	45	47
	Shallow Water	40	110
Grand Falls-Windsor	Bog	30	357
	Fen	61	194
	Marsh	45	102
	Swamp	30	47
	Shallow Water	21	52
Deer Lake	Bog	31	236
	Fen	54	121
	Marsh	24	19
	Swamp	40	56
	Shallow Water	23	68
Gros Morne	Bog	38	779
	Fen	31	98
	Marsh	31	50
	Swamp	42	48
	Shallow Water	27	64
Goose Bay	Bog	28	395
	Fen	29	139
	Marsh	21	78
	Swamp	23	35
	Shallow Water	11	19

Wetland Classification in NL (up to now)

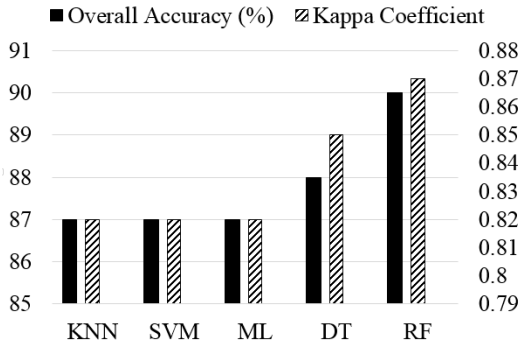
Satellite data

- Optical
  - RapidEye
  - Landsat-8 (free)
  - Sentinel-2 (free)
  - ASTER (free)
- SAR
  - RADARSAT-2 (free)
  - ALOS-1 (free)
  - ALOS-2
  - Sentinel-1 (free)
  - TerraSAR-X
- Aerial
  - Canadian Digital Elevation Model (CDEM)

Wetland Classification in NL (up to now)

Preliminary analyses

Comparison between classification algorithms



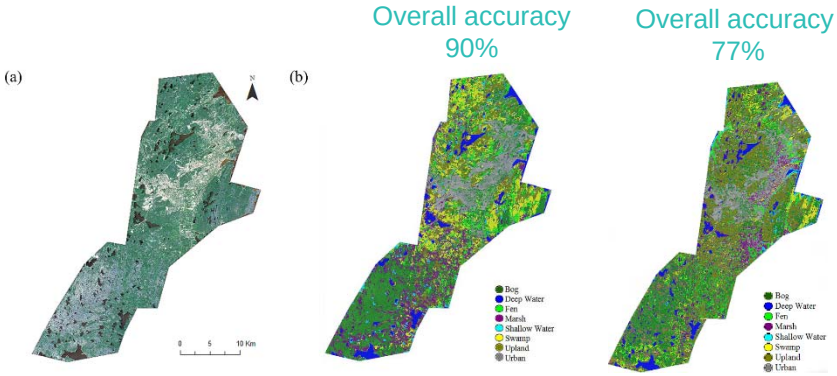
Evaluation of confusion matrix

Confusion matrix in terms of the number of pixels for the classification using the Random Forest algorithm with the User Accuracy, Producer Accuracy, errors of Commission ,and error of Omission (in %).

		Reference Data										
		B	F	M	SW	S	Up	DW	Ur	Total	C	UA
Classified Data	B	**20279**	4241	1476	0	590	0	0	83	26669	24	76
	F	1672	**7368**	841	0	987	0	0	0	10868	32	68
	M	541	70	**3941**	92	0	1295	0	0	5939	34	66
	SW	0	0	0	**1445**	0	0	60	0	1505	4	96
	S	78	740	859	0	**3470**	2316	0	32	7495	54	46
	Up	0	682	0	0	178	**24304**	0	0	25164	3	97
	DW	0	0	0	0	0	0	**69312**	0	69312	0	100
	Ur	0	0	0	0	0	0	0	**19340**	19340	0	100
	Total	22570	13101	7117	1537	5225	27915	69372	19455	**166292**		
	O	10	44	45	6	34	13	0	1		**OA= 91**	
	PA	90	56	66	94	66	87	100	99		**K= 0.87**	

OA: Overall Accuracy	B: Bog	S: Swamp	C: Commission
K: Kappa Coefficient	F: Fen	Up: Upland	O: Omission
PA: Producer Accuracy	M: Marsh	DW: Deep Water	
UA: User Accuracy	SW: Shallow Water	Ur: Urban	

Pixel-based vs. object-based method

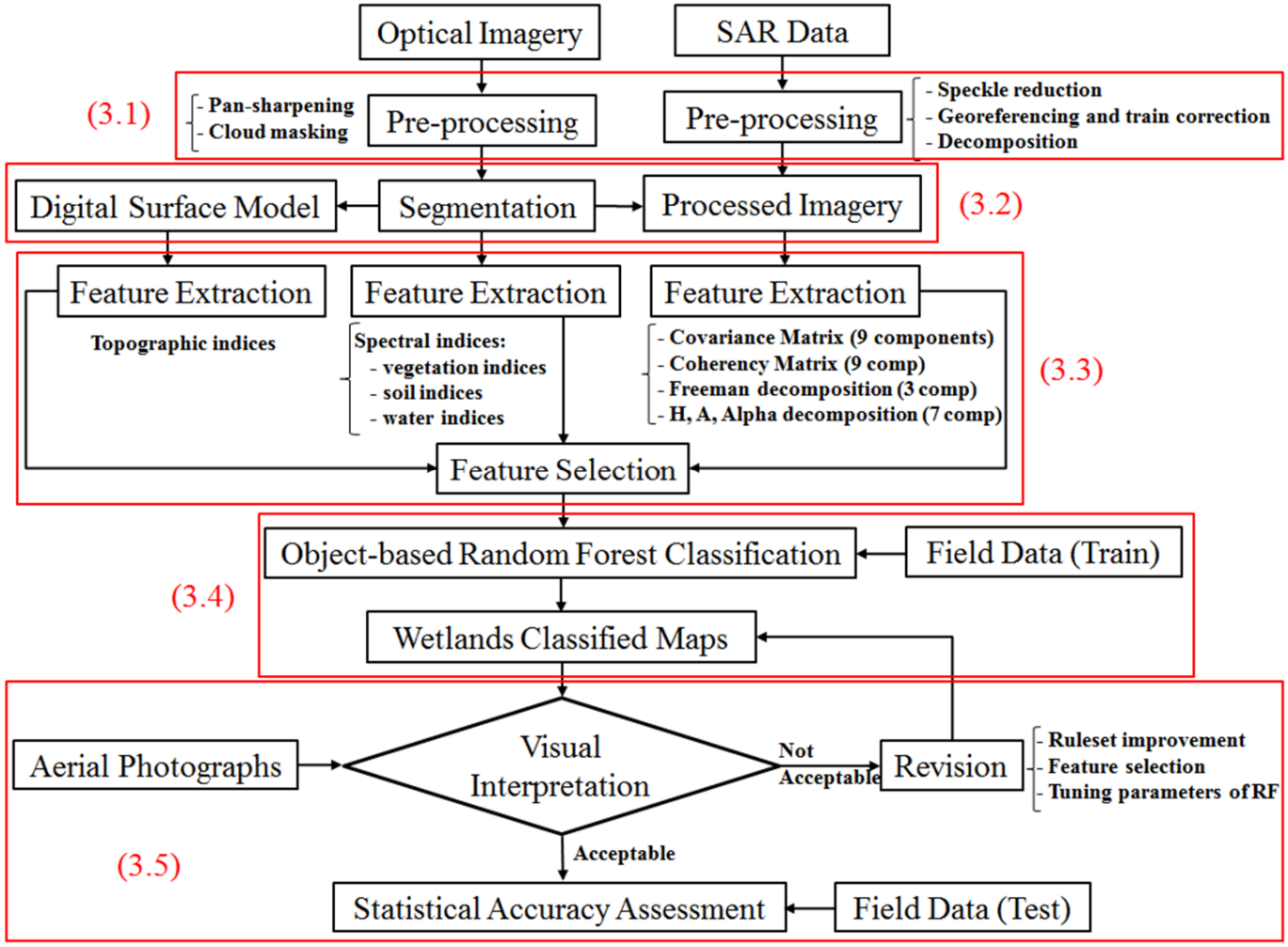


Evaluation of multi-temporal satellite data

Accuracy	June (2015/06/19)	August (2015/08/15)	November (2015/11/26)	Combination of multi-date images
OA (%)	86	88	81	88
APA (%)	60	64	56	68
AUA (%)	57	60	53	63

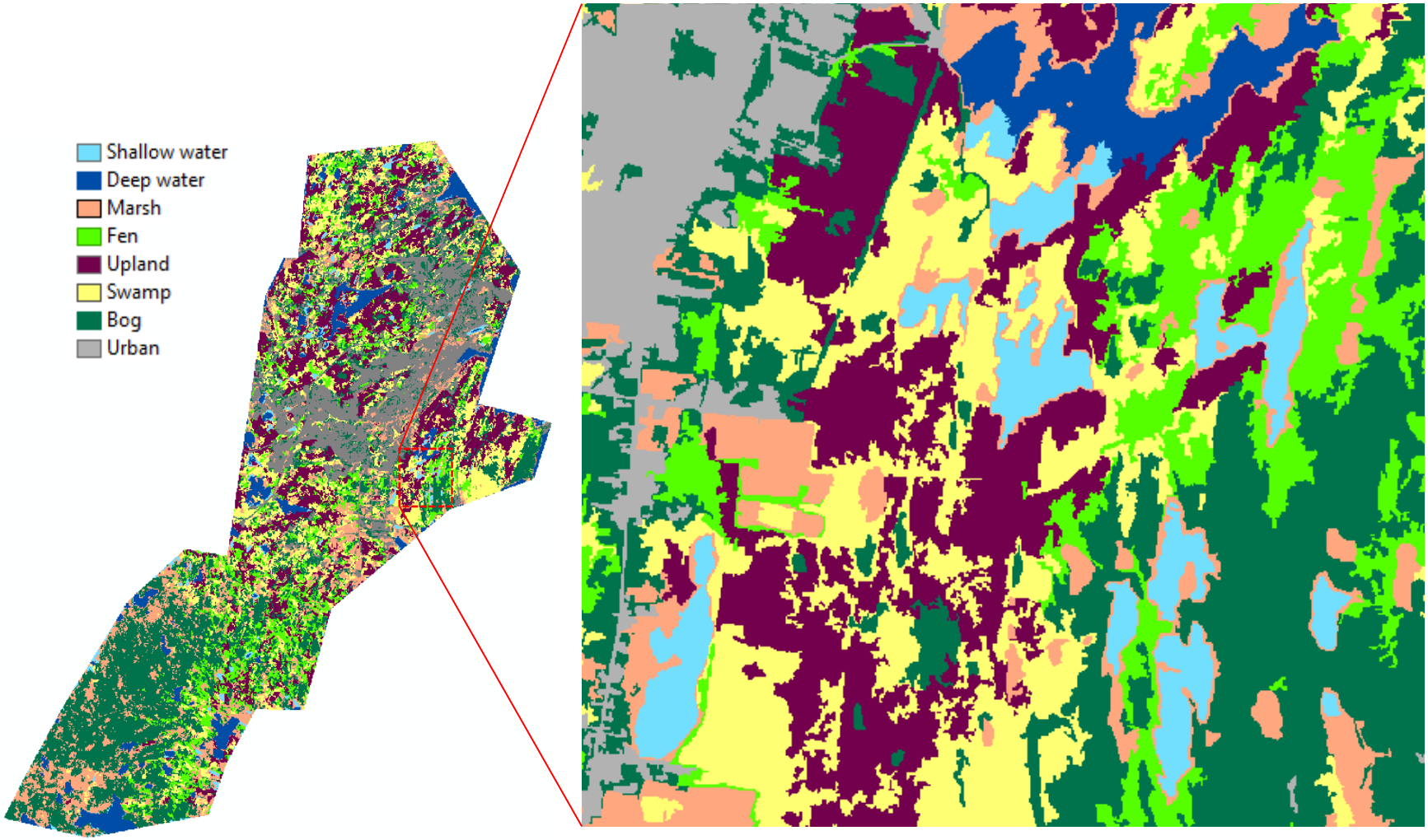
Wetland Classification in NL (up to now)

General method



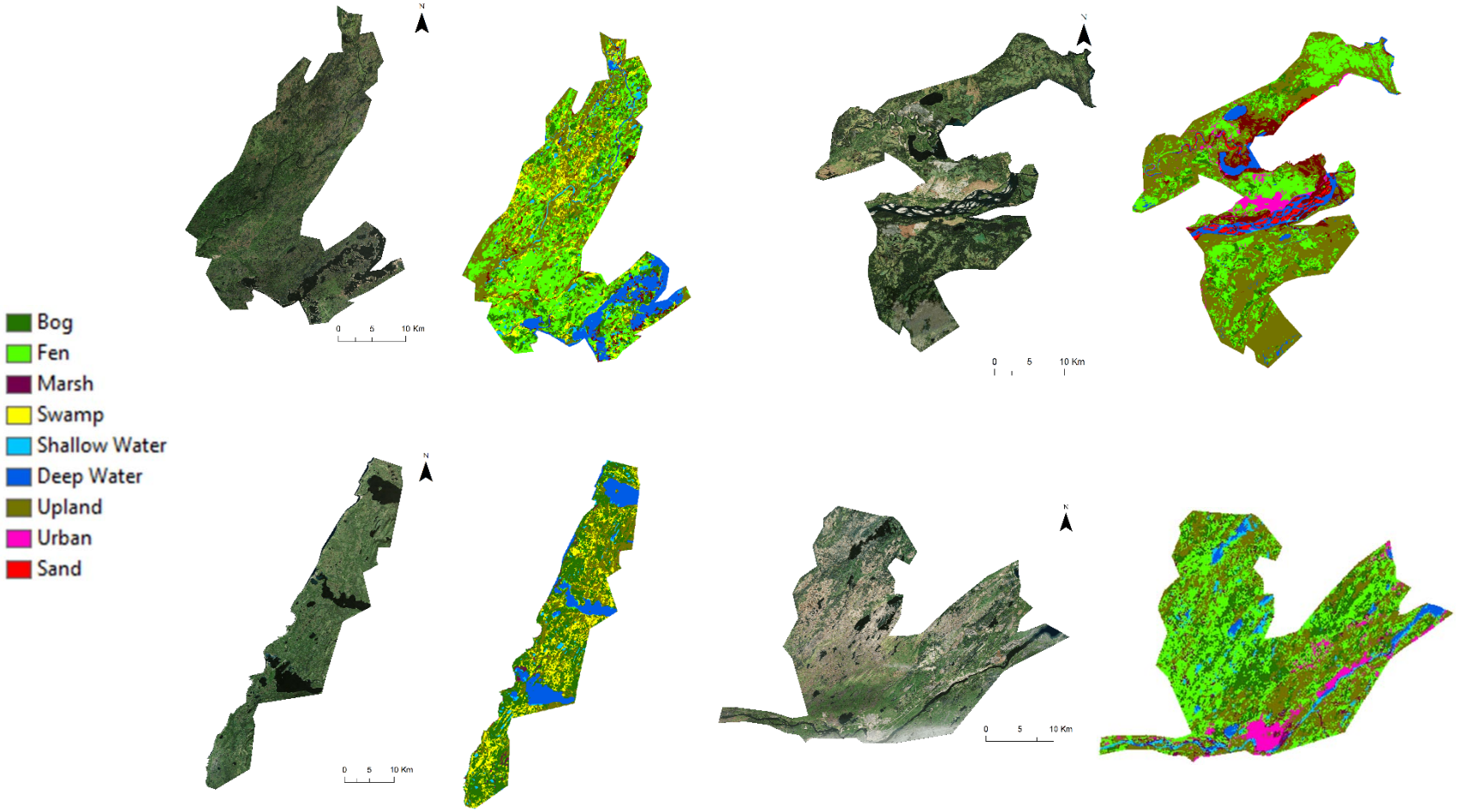
Wetland Classification in NL (up to now)

Wetland classified maps



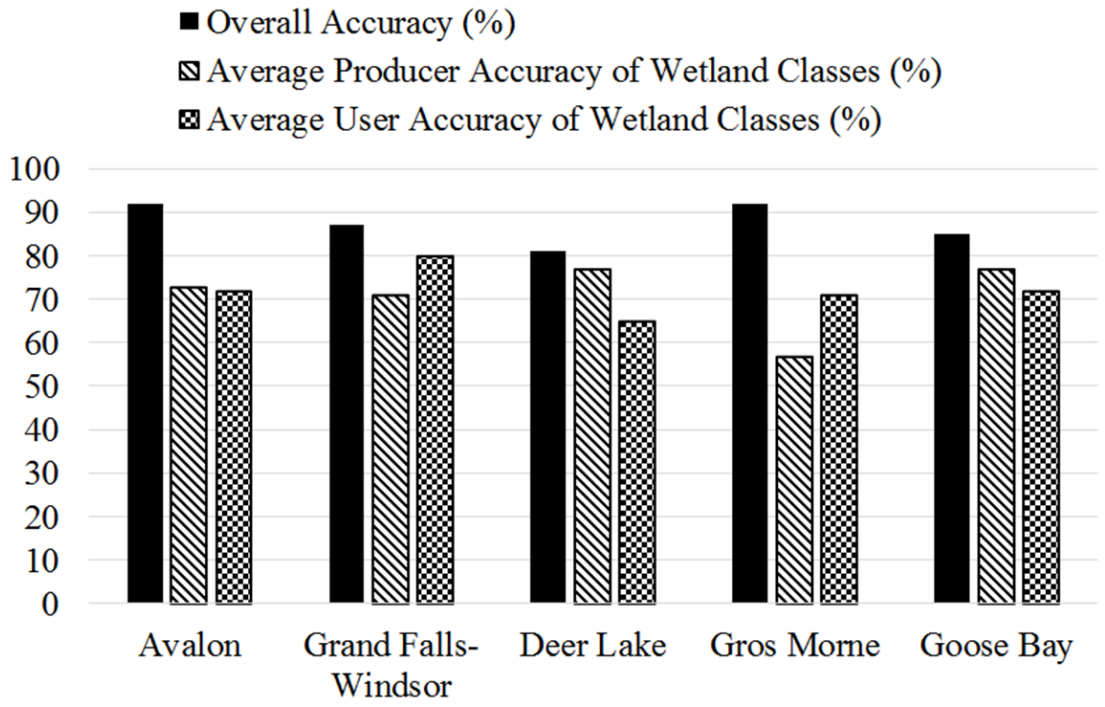
Wetland Classification in NL (up to now)

Wetland classified maps



Wetland Classification in NL (up to now)

Classification accuracies



Wetland Classification in NL (up to now)

Other analysis (spectral analysis of wetlands)

Evaluated optical features

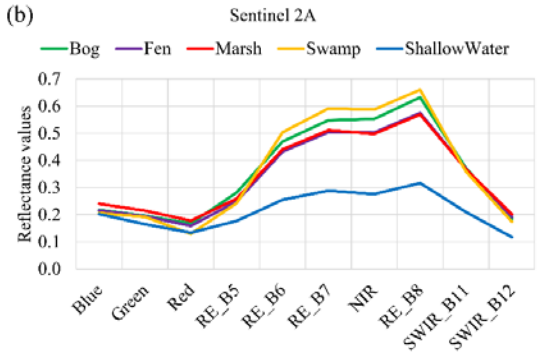
The spectral bands of RapidEye, Sentinel 2A, ASTER, and Landsat 8 used in this study (The wavelength range for each band is provided in the parentheses, and is in micrometers).

RapidEye	Sentinel 2A	ASTER	Landsat 8
B1_Blue (0.44-0.51)	B2_Blue (0.46-0.52)	B1_Green (0.52-0.6)	B2_Blue (0.45-0.51)
B2_Green (0.52-0.6)	B3_Green (0.54-0.58)	B2_Red (0.63-0.69)	B3_Green (0.53-0.59)
B3_Red (0.63-0.69)	B4_Red (0.65-0.68)	B3N_NIR (0.76-0.86)	B4_Red (0.64-0.67)
B4_RE (0.69-0.73)	B5_RE (0.698-0.712)	B10_TIR (8.13-8.48)	B5_NIR (0.85-0.88)
B5_NIR (0.76-0.85)	B6_RE (0.733-0.747)	B11_TIR (8.48-8.83)	B6_SWIR (1.57-1.67)
	B7_RE (0.773-0.793)	B12_TIR (8.93-9.28)	B7_SWIR (2.11-2.29)
	B8_NIR (0.784-0.9)	B13_TIR (10.25-10.95)	B10_TIR (10.6-11.19)
	B8A_RE (0.855-0.875)	B14_TIR (10.95-11.65)	
	B11_SWIR (1.565-1.655)		
	B12_SWIR (2.1-2.28)		

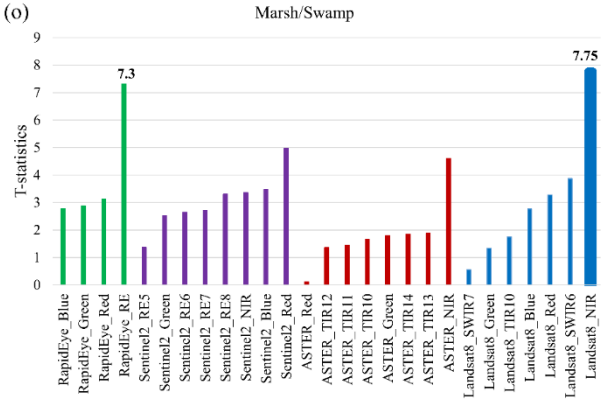
The spectral indices, textural and ratio features evaluated in this study for separability analyses of wetland types.

Spectral indices	$Brightness$, $NDWI=\frac{Green-NIR}{Green+NIR}$, $DVI=NIR-Red$, $NDVI=\frac{NIR-Red}{NIR+Red}$, $RE\text{-}NDVI=\frac{NIR-RE}{NIR+RE}$, $NDSI=\frac{SWIR-NIR}{SWIR+NIR}$, $SAVI=\frac{(1+L)(NIR-Red)}{NIR+Red+L}$; $L=0.5$
Ratio features	$\frac{Blue}{Brightness}$, $\frac{Green}{Brightness}$, $\frac{Red}{Brightness}$, $\frac{RE}{Brightness}$, $\frac{NIR}{Brightness}$, $\frac{SWIR}{Brightness}$
Texture features	Standard deviation of the polygons obtained from all spectral bands of the satellites.

Visual analysis (spectral signature)



Statistical analysis



Best optical spectral bands (summary)

The most useful spectral bands for discriminating between each pairs of wetland classes in late Spring (June) using two distance measures. The spectral bands are ordered based on their separability measures (the spectral bands indicated in the upper right half of the table and the lower left half of the table were obtained by the T-statistics and U-statistics, respectively).

	Bog	Fen	Marsh	Swamp	Shallow Water
Bog	×	Landsat8 NIR RapidEye RE ASTER NIR RapidEye NIR	RapidEye RE Landsat8 NIR	RapidEye Red	RapidEye NIR
Fen	Sentinel2 RE5 Landsat8 NIR	×	Landsat8 NIR RapidEye RE	RapidEye Red	RapidEye NIR
Marsh	Landsat8 NIR RapidEye RE	RapidEye RE	×	Landsat8 NIR RapidEye RE	RapidEye RE
Swamp	Landsat8 Red	Sentinel2 RE7 Sentinel2 RE6 Sentinel2 NIR ASTER NIR Sentinel2 RE8 RapidEye Red	Landsat8 NIR RapidEye RE	×	RapidEye NIR
Shallow Water	Landsat8 NIR Landsat8 SWIR6	Landsat8 NIR Landsat8 SWIR6 Landsat8 SWIR7	Sentinel2 RE6	Sentinel2 RE6	×

Wetland Classification in NL (up to now)

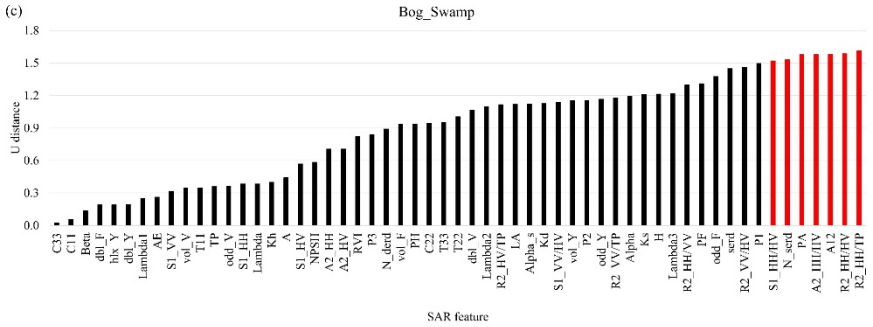
Other analysis (backscattering analysis of wetlands)

Evaluated SAR features

SAR features investigated for separability analysis of wetland classes **(80 features in total).**

Sentinel-1	
(5 features): horizontal transmit and horizontal receive polarization of Sentinel-1 (S1_HH), horizontal transmit and vertical receive polarization of Sentinel-1 (S1_HV), vertical transmit and vertical receive polarization of Sentinel-1 (S1_VV), S1_HH/HV= $\frac{\lvert S_{HH}\rvert^2}{\lvert S_{HV}\rvert^2}$, S1_VV/HV= $\frac{\lvert S_{VV}\rvert^2}{\lvert S_{HV}\rvert^2}$	
ALOS-2	
(3 features): horizontal transmit and horizontal receive polarization of ALOS-2 (A2_HH), horizontal transmit and vertical receive polarization of ALOS-2 (A2_HV), A2_HH/HV= $\frac{\lvert S_{HH}\rvert^2}{\lvert S_{HV}\rvert^2}$	
RADARSAT-2	
Covariance matrix (16 features)	Diagonal elements (C11=$\lvert S_{HH}\rvert^2$, C22=$\lvert S_{HV}\rvert^2$, C33=$\lvert S_{VV}\rvert^2$), Total Power (TP = $\lvert S_{HH}\rvert^2 + 2\lvert S_{HV}\rvert^2 + \lvert S_{VV}\rvert^2$), Off-diagonal elements, Polarization ratios (R2_HH/HV= $\frac{\lvert S_{HH}\rvert^2}{\lvert S_{HV}\rvert^2}$, R2_VV/HV= $\frac{\lvert S_{VV}\rvert^2}{\lvert S_{HV}\rvert^2}$, R2_HH/VV= $\frac{\lvert S_{HH}\rvert^2}{\lvert S_{VV}\rvert^2}$, R2_HH/TP= $\frac{\lvert S_{HH}\rvert^2}{TP}$, R2_HV/TP= $\frac{\lvert S_{HV}\rvert^2}{TP}$, R2_VV/TP= $\frac{\lvert S_{VV}\rvert^2}{TP}$)
Coherency matrix (9 features)	Diagonal elements (T11, T22, T33), Off-diagonal elements
Freeman-Durden (3 features)	Surface scattering (odd_F), Double-bounce scattering (dbl_F), Volume scattering (vol_F)
Van Zyl (Van Zyl, 1989), (3 features)	Surface scattering (odd_V), Double-bounce scattering (dbl_V), Volume scattering (vol_V)
Yamaguchi (Yamaguchi et al., 2005), (4 features)	Surface scattering (odd_Y), Double-bounce scattering (dbl_Y), Volume scattering (vol_Y), Helix scattering (hlx_Y)
Krogager (Krogager, 1990), (3 features)	Sphere scattering (Ks), Diplane scattering (Kd), Helix scattering (Kh)
Cloude-Pottier (7 parameters)	Anisotropy (A), Entropy (H), Alpha, Beta, Delta, Gamma, Lambda
Touzi (4 features)	Symmetric scattering type magnitude (Alpha_s), Symmetric scattering type phase (P_Alpha_s), Orientation angle (ψ), Helicity (τ)
Eigen value parameters (23 features)	First pseudo probability (P1 = $\frac{\lambda_1}{\lambda_1+\lambda_2+\lambda_3}$), Second pseudo probability (P2 = $\frac{\lambda_2}{\lambda_1+\lambda_2+\lambda_3}$), Third pseudo probability (P3 = $\frac{\lambda_3}{\lambda_1+\lambda_2+\lambda_3}$), First Eigen value (Lambda1), Second Eigen value (Lambda2), Third Eigen value (Lambda3), Shannon entropy (SH), Normalized Shannon entropy (NSH), Polarimetry Shannon entropy (PSH), Normalized polarimetry Shannon entropy (NPSH), Intensity Shannon entropy (ISH), Normalized intensity Shannon entropy (NISH), Anisotropy (AE), Luenburg Anisotropy (LA), Anisotropy 12 (A12), Single-bounce eigenvalues relative difference (serd), Normalized single-bounce eigenvalues relative difference (N_serd), Double-bounce eigenvalues relative difference (derd), Normalized double-bounce eigenvalues relative difference (N_derd), Polarization asymmetry (PA), Polarization fraction (PF), Radar Vegetation Index (RVI), Pedestal Height (PH)

Statistical analysis



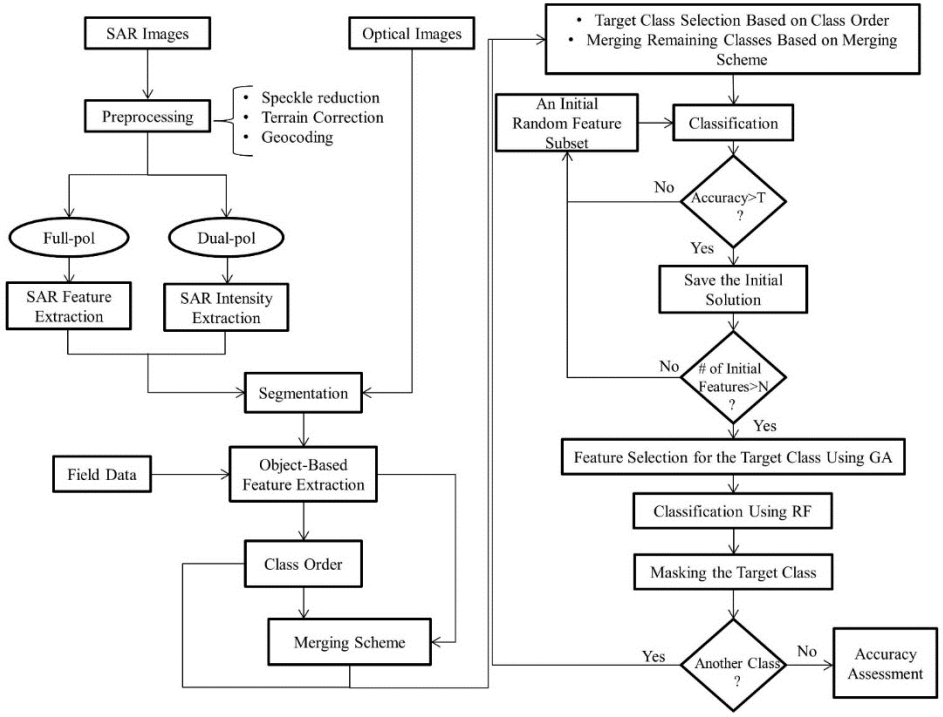
Best SAR features and decomposition methods(summary)

The most useful SAR features (provided in the upper right half of the table) and the decomposition methods (provided in the lower left half of the table) for discriminating between each pair of wetland classes. The features and decomposition methods are ordered based on their separability measures (refer to Table 5.3 for the acronyms of the selected SAR features).

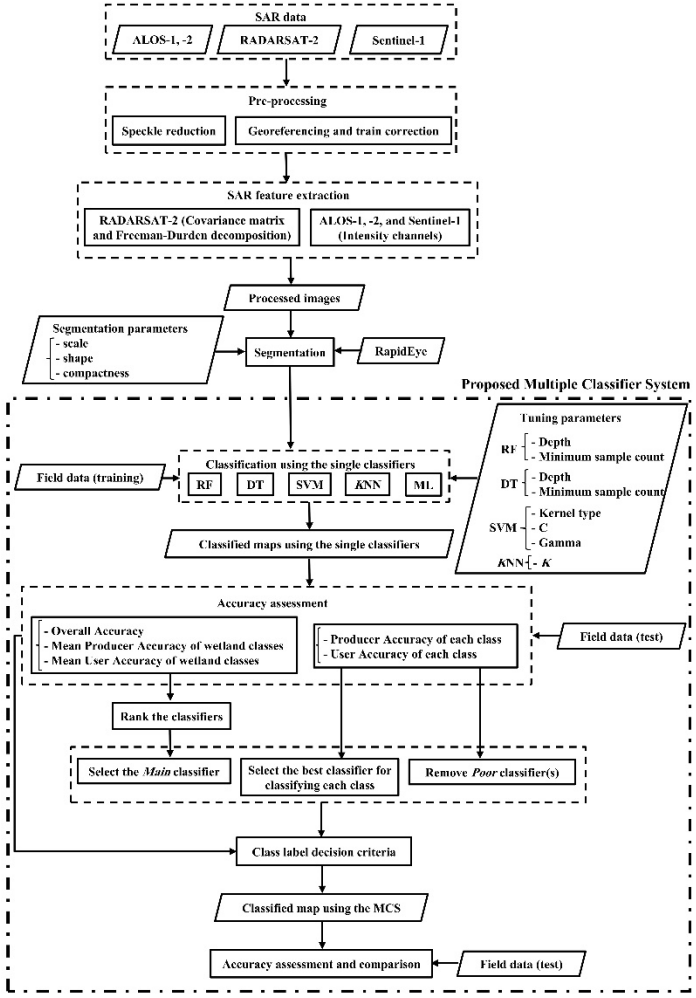
	Bog	Fen	Marsh	Swamp	Shallow Water
Bog	×	Alpha Alpha_s dbl_F H S1_HH/HV odd_Y PA	Alpha_s Alpha vol_F A R2_HV/TP P2 S1_HH/HV	R2_HH/TP R2_HH/HV A12 A2_HH/HV PA N_serd S1_HH/HV	A N_derd R2_HH/VV
Fen	H/A/Alpha Freeman-Durden	×	S1_HH/HV N_derd A R2_HH/HV R2_HH/TP R2_HV/TP dbl_F	A2_HH/HV serd R2_HH/HV R2_HH/TP N_serd A12 P1	N_derd A R2_HH/VV R2_HH/HV N_serd serd R2_VV/HV
Marsh	H/A/Alpha Freeman-Durden	Freeman-Durden H/A/Alpha	×	R2_HH/HV R2_HV/TP R2_HH/TP A2_HV serd N_derd N_serd	A S1_VV/HV N_derd R2_VV/TP R2_VV/HV N_serd PF serd
Swamp	H/A/Alpha	Freeman-Durden	H/A/Alpha Freeman- Durden	×	R2_HH/HV N_derd A serd N_serd R2_VV/HV PF R2_HH/TP
Shallow Water	H/A/Alpha Freeman-Durden	-	H/A/Alpha	-	×

Wetland Classification in NL (up to now)

Other analysis (Advanced classification algorithms to improve the accuracy)



Mahdavi et al., 2018



Amani et al., 2018

Selected Journal Publications

- Amani, M., Salehi, B., Mahdavi, S., Granger, J., & Brisco, B. (2017). “Wetland classification in Newfoundland and Labrador using multi-source SAR and optical data integration”. GIScience & Remote Sensing, 54(6), 779-796.
- Amani, M., Salehi, B., Mahdavi, S., Granger, J. E., Brisco, B., & Hanson, A. (2017). “Wetland Classification Using Multi-Source and Multi-Temporal Optical Remote Sensing Data in Newfoundland and Labrador, Canada”. Canadian Journal of Remote Sensing, 43(4), 360-373.
- Mahdavi, S., Salehi, B., Amani, M., Granger, J. E., Brisco, B., Huang, W., & Hanson, A. (2017). “Object-based classification of wetlands in Newfoundland and Labrador using multi-temporal PolSAR data”. Canadian Journal of Remote Sensing, 43(5), 432-450.
- Mahdavi, S., Salehi, B., Granger, J., Amani, M., & Brisco, B. (2017). “Remote sensing for wetland classification: a comprehensive review”. GIScience & Remote Sensing, 1-36.
- Amani, M., Salehi, B., Mahdavi, S., Brisco, B., & Shehata, M. (2018). “A Multiple Classifier System to improve mapping complex land covers: a case study of wetland classification using SAR data in Newfoundland, Canada”. International Journal of Remote Sensing, 1-14.
- Amani, M., Salehi, B., Mahdavi, S., & Brisco, B. (2018). “Spectral analysis of wetlands using multi-source optical satellite imagery”. ISPRS Journal of Photogrammetry and Remote Sensing, 144, 119-136.

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- Dr. Brian Brisco - Canada Center for Mapping and Earth Observation

Wetland Classification in NL (Next Step)

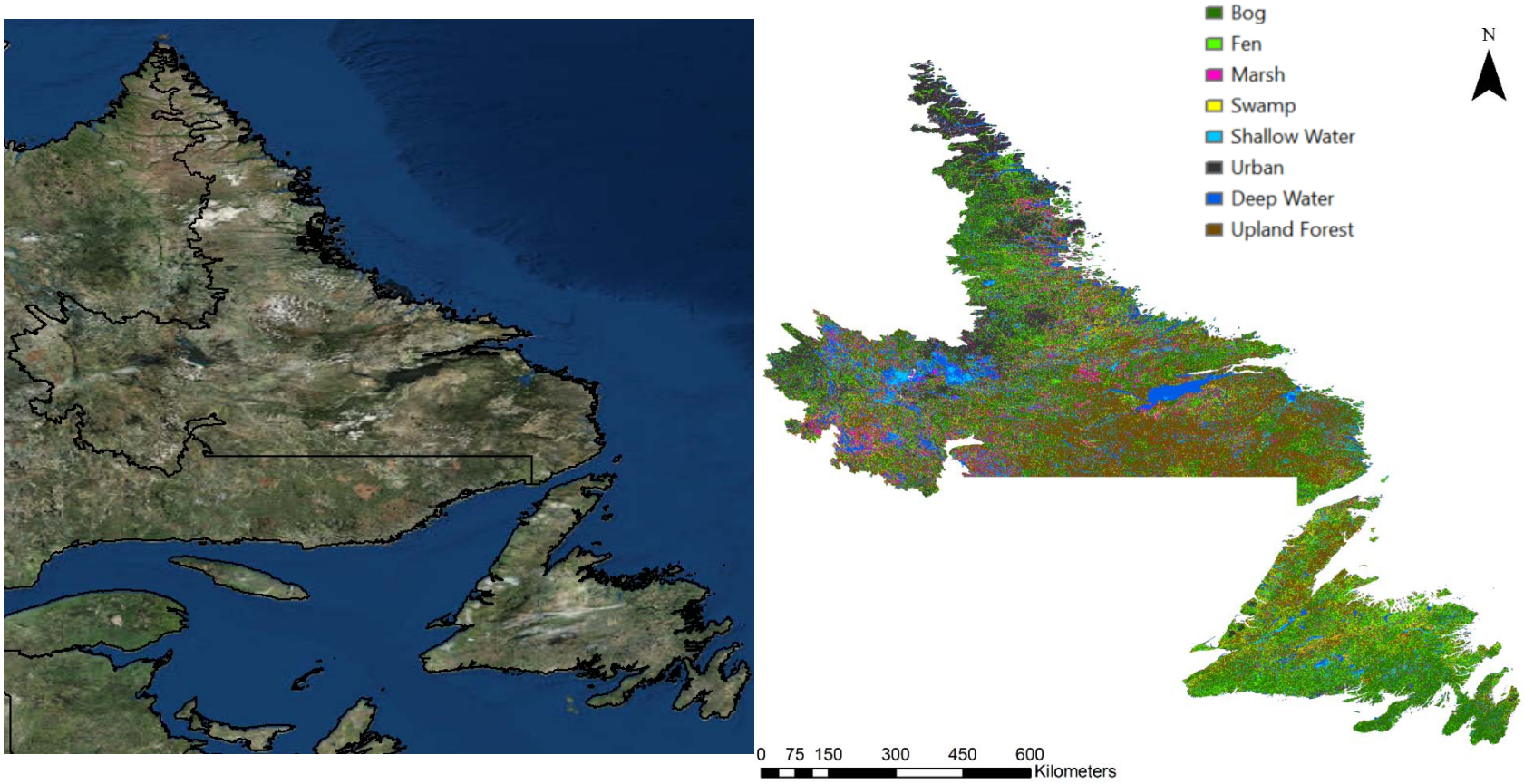
Limitation of the previous works

- Wetland maps from only 5 pilot sites (1% of the province in total)
- No wetland map from the entire province
- Did not evaluate the changes over years and did not estimate the amount of loss/gain in wetland areas
- Did not consider most of the non-wetland classes
- Conducted solely based on remote sensing
- Some of the satellite data were not free

Wetland Classification in NL (Next Step)

Preliminary map

- NL-wide wetland map in 2018 using multi-date landsat-8 imagery



Wetland Classification in NL (Next Step)

How to improve the accuracy of maps

- Use a combination of optical (Landsat-8+Sentinel-2) and SAR (Sentinel-1) data
- Include more field data
- Include more non-wetland classes
- Remove small classified areas to make the maps less noisy
- Produce wetland maps each year and evaluate the changes, gain, and loss in wetland areas over time
- Relate the results to the other variables (carbon storage, ducks migration, etc.)

Wetland Classification in NL (Next Step)

Support / Collaboration

Wetland, Long Pond, St. John's

Thanks

meisam.amani
@woodplc.com