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Using IKONOS Imaging to Map Wetlands in Georgian Bay

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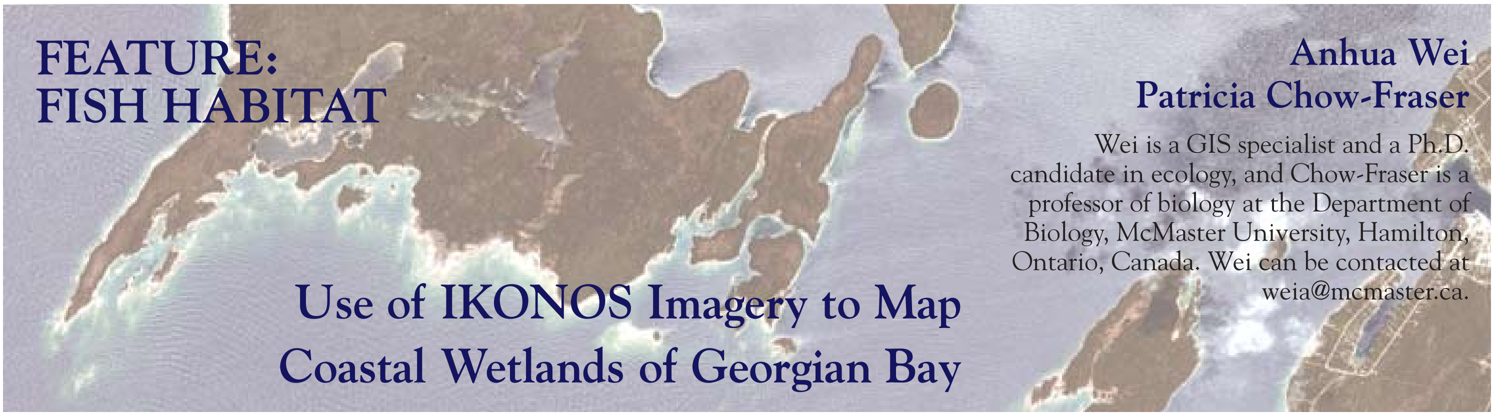

FEATURE:
FISH HABITAT

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Use of IKONOS Imagery to Map Coastal Wetlands of Georgian Bay

ABSTRACT: Wetlands throughout North America have been diminished in quantity and quality because of human activities, and it is therefore important that fishery managers monitor changes in supply of this critical fish habitat. Use of traditional field-based methods to detect and record the change in aquatic vegetation in Great Lakes wetlands is a daunting task because wetlands are extensive and widely distributed along the Great Lakes shoreline. Mapping wetlands for such a large geographic area necessitates the use of remote sensing technology to obtain an accurate inventory of these ecosystems. The objective of this study was to explore the capabilities of using IKONOS satellite imagery to map different types of aquatic vegetation and habitat features in Great Lakes wetlands. We acquired imageries for Fathom Five National Marine Park in Lake Huron and an area of eastern Georgian Bay in 2002 and chose 11 wetlands for habitat mapping with remote sensing software. The comparison of results of the image analysis with reference data indicated that the overall accuracy of mapping was approximately 90%. This suggests that high resolution IKONOS imagery can be used effectively to monitor the change in aquatic vegetation and thus track alterations in fish habitat in Great Lakes coastal marshes.

Uso de la colección de imágenes de IKONOS para mapear los humedales de la Bahía Georgiana

RESUMEN: Los humedales de América del Norte han disminuido en cantidad y calidad por las actividades humanas, por lo que es importante que los administradores de recursos pesqueros evalúen estos cambios en este hábitat crítico. El uso de métodos tradicionales para detectar y registrar cambios de la vegetación acuática en los humedales de los Grandes Lagos es una tarea descomunal, debido a que los humedales son extensos y están ampliamente distribuidos alrededor de la línea de costa. Para inventariar con precisión ecosistemas de humedales en áreas geográficas extensas es necesario el uso de tecnología de sensoría remota. El objetivo de este estudio fue explorar la potencialidad de las imágenes tomadas por el satélite IKONOS para dibujar mapas de los diferentes tipos de vegetación y características del hábitat de los humedales de los Grandes Lagos. Adquirimos imágenes del año 2002 para el Parque Marino Nacional Fathom Five, en el Lago Hurón, y el área Este de la Bahía Georgiana y seleccionamos 11 humedales para trazar mapas de hábitat con programas computacionales especializados en sensoría remota. La comparación de los resultados de los análisis de las imágenes contra datos de referencia indica que en general los mapas tienen una certeza cercana al 90%. Lo anterior sugiere que las imágenes de alta resolución tomadas por el satélite IKONOS pueden utilizarse para monitorear cambios en la vegetación y rastrear modificaciones en el hábitat de los humedales costeros en los Grandes Lagos.

INTRODUCTION

Coastal wetlands are known to be very important to the fisheries of the Laurentian Great Lakes because they provide spawning and nursery habitat for wetland-dependent species that include a large number of the commercially and recreationally important taxa (e.g., Jude and Pappas 1992; Wei et al. 2004). The U.S. Nature Conservancy estimated that about 80% of the approximately 200 fish species found in the Great Lakes use the near-shore areas for at least part of the year and directly depend on coastal wetlands for some part of their life cycles (Chow-Fraser and Albert 1999). Both government agencies and non-governmental organizations have now acknowledged the important ecological values and functions of these coastal ecosystems (Maynard and Wilcox 1997; Chow-Fraser and Albert 1999), and have devoted considerable effort over the past two decades towards developing strategies to protect and restore these habitats at a basin-wide scale.

An important first step in the management of coastal wetlands is the development of a basin-wide inventory that can be updated at regular intervals. The wide distribution of wetlands in the Great Lakes basin necessitates the use of remote sensing technology, such as aerial photographs or satellite images. With high-resolution color-infrared aerial photographs, detailed habitat features can be distinguished from each other, but the costs associated with this can be sufficiently high that updates can only be carried out at 10-year intervals (e.g., U.S. National Wetland Inventory; Wilen et al. 2002). By comparison, satellite data (e.g., Landsat 5 or 7) can be more cost-effective because of the large spatial coverage captured in each satellite scene, but the resolution is often too coarse to discriminate habitat features such as type of aquatic plants at small spatial scales (e.g., Mumby and Edwards 2002). A third alternative, IKONOS (derived from the Greek word for "image"), is a high-resolution satellite capable of simultaneously collecting 1-m panchromatic (single band or monochrome imagery) and 4-m multispectral images (4 bands) over a relatively large geographic area. Suitable for mapping wetland habitat at much smaller spatial scales (e.g., < 10 m) than has been possible with other satellite imagery such as Landsat satellite, IKONOS has been used successfully in several coastal projects in marine systems (e.g., Mumby and Edwards 2002; Andréfouët et al. 2003; Riegl and Purkis 2005).

To date, no study has detailed the use of IKONOS in freshwater coastal areas, such as the Laurentian Great Lakes. Our objective was to use IKONOS imagery to map detailed habitat features in freshwater wetlands in a small region of Lake Huron and Georgian Bay. We first conducted ground surveys of these wetlands, and then used the location of ground features (emergent vegetation, submergent vegetation, open water, etc.) to guide the classification of aquatic vegetation cover in the IKONOS image. Finally we assessed the overall accuracy of this classification and evaluated the potential for using IKONOS imagery to map Great Lakes aquatic habitat at a basin-wide scale.

METHODS

Site description

Eleven wetland sites in the Georgian Bay region were examined (Table 1 and Figures 1 and 2). Ten of the 11 wetlands were found in Fathom Five National Marine Park (FFNMP), which is located at the boundary zone between Georgian Bay to the east and Lake Huron to the west. Two of the wetlands in this study are located on the mainland at the northern tip of the Bruce Peninsula: Hay Bay wetland complex and Ragged Bight wetland. In addition to natural stressors such as water level fluctuations, these wetlands are also affected by nutrient and sediment loading from their watersheds. The remaining FFNMP wetlands are located on two islands, the larger of which is Cove Island and the smaller is Russel Island. Most of these island wetlands are unaffected by human-induced stressors such as nutrient and sediment enrichment (Chow-Fraser, unpub. data). Herman's Bay is a very small (3-ha) pristine embayment, which is hydrologically attached to eastern Georgian Bay through Twelve Mile Bay (Figures 1 and 2). The shoreline is undeveloped and there is no obvious anthropogenic impact. Plant life in this marsh is extremely abundant and the distributional pattern of broad groups of wetland plants is distinct. These characteristics makes Herman's Bay an ideal site to explore the potential capability of IKONOS for detecting wetland plants at the level of species assemblages. Plant covers from Herman's Bay have been identified and classified into four types based on ground truth data collected in August 2004: (1) meadow, (2) emergent zone dominated by *Scirpus*, (3) emergent zone dominated by *Pontederia*, and (4) a mixed floating-emergent zone dominated by *Nuphar* and *Sparganium*.

Principles of mapping wetlands with remote sensing imagery

Satellite sensors can record reflectance from Earth surface features. Many of these features have distinctive spectral reflectance, which is referred to as spectral response pattern or spectral "signature." Automated image classification uses the spectral information represented by the digital numbers in satellite imagery and attempts to assign all pixels (points) in the image to particular classes based on this spectral information (e.g., open water, submergent vegetation, or emergent vegetation). Figure 3 illustrates a stage in a typical procedure used to map wetland habitat with remote sensing techniques. Initially, geographic coordinates (i.e., latitude and longitude acquired with GPS units) must be collected in the field, which will serve as reference (ground truth) data to classify the major features being mapped (i.e., open water, submergent vegetation, emergent vegetation in this hypothetical wetland). Based on these field data, representative areas can then be selected by analysts on satellite imagery (Figure 3a). Supervised by analysts and trained by the representative areas, image pixels with similar reflectance patterns are grouped into the same habitat class (Figure 3 b-c).

Procedures used to map aquatic habitat in FFNMP wetlands

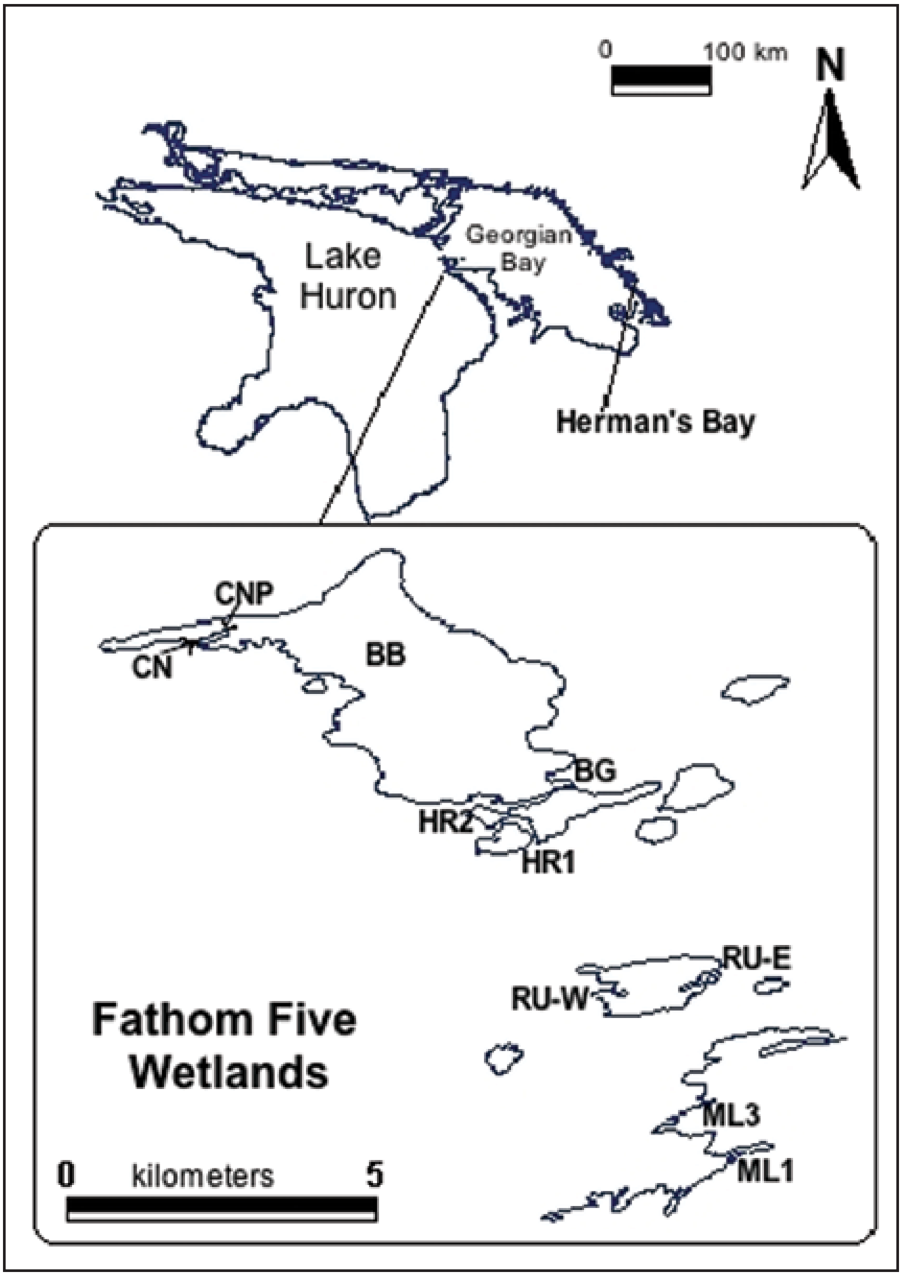
The classification procedures are similar to those for mapping terrestrial systems which can be found in most remote sensing textbooks. The procedures used to map FFNMP wetlands are summarized as follows:

(a) **Acquring IKONOS imagery.** The relevant imageries (Figure 2) were separately acquired by Parks Canada (for wetlands in FFNMP) and the Georgian Bay Association Foundation (GBA Foundation) (for Herman's Bay) from Space Imaging (Thornton, CO 80241) in 2002. In each case, both Parks Canada and GBA Foundation indicated the area of interest by providing Space Imaging

Table 1. Summary of sites and a brief description of likely impact.

Site		Code	Area (ha)	Type of impact
1.	Boat Passage	BG	16.7	Low human impact (Boat channel)
2.	Cove Island Inner Harbour	HR1	5.7	No obvious human impact
3.	Cove Island Outer Harbour	HR2	2.9	No obvious human impact
4.	Cove Island North	CN	16.4	No obvious human impact
5.	Cove Island North Pond	CNP	1.4	No obvious human impact, declining water level
6.	Bass Bay	BB	39.0	No obvious human impact, declining water level
7.	Hay Bay One	ML1	7.7	High human impact (public beach, high cottage density)
8.	Ragged Bight	ML2	3.2	Moderate human impact
9.	Russel Island East	RU-E	2.9	No obvious human impact, declining water level
10.	Russel Island West	RU-W	3.8	No obvious human impact, declining water level
11.	Herman's Bay	HM	3.0	No obvious human impact

Figure 1. Map of study wetland sites in Georgian Bay. See Table 1 for key to site codes.

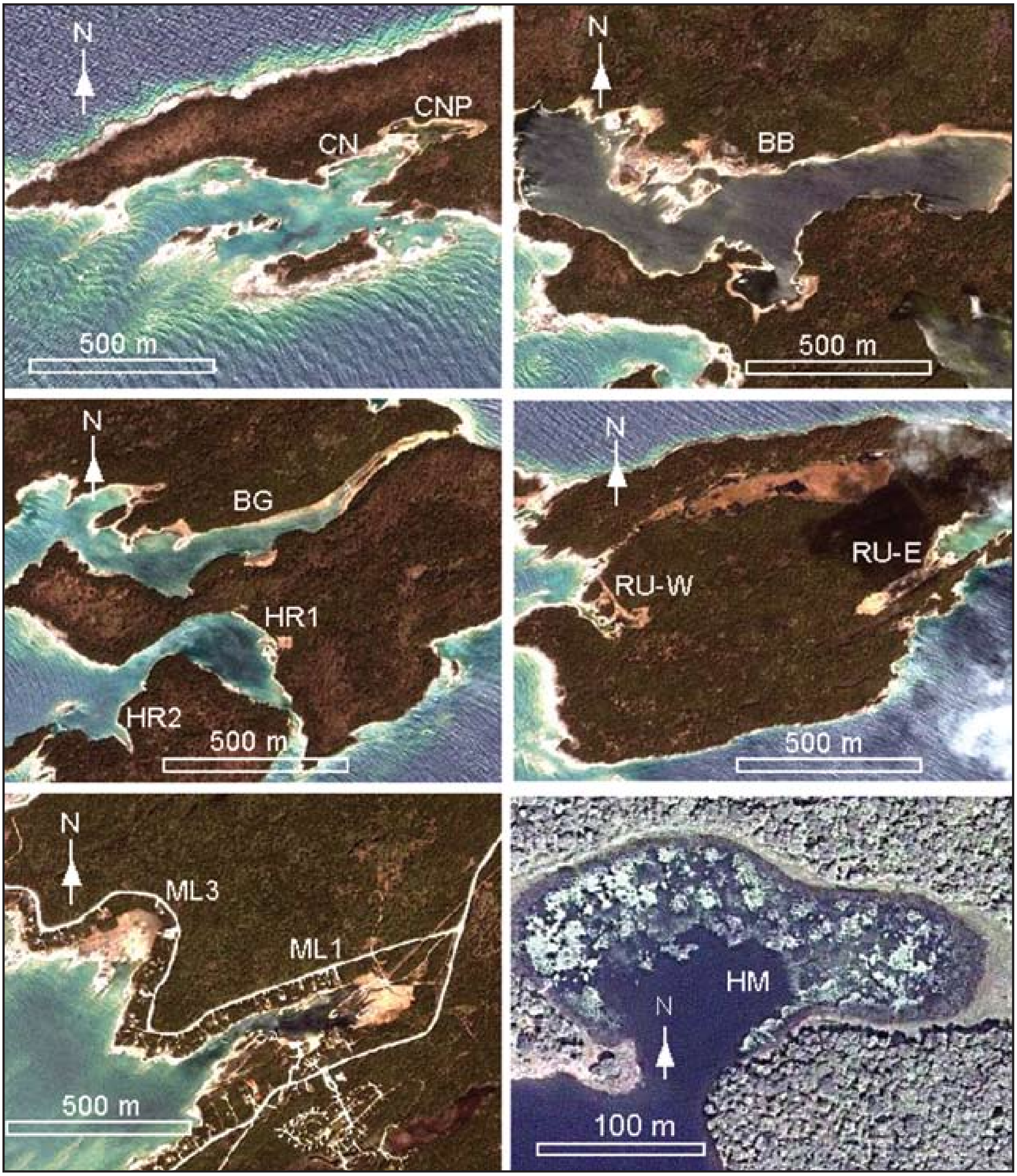


with a set of geographic coordinates, as well as the preferred season.

(b) **Collecting ground-truth data.** First, we determined the number of habitat classes to be mapped. For FFNMP wetlands, we determined that five habitat features based on the dominant vegetation type and geological features would be suitable: (1) emergent vegetation, (2) submersed aquatic vegetation (SAV), (3) rock/shrubs, (4) rock, and (5) open water. However, for Herman's Bay we determined that five zones based on the distinct distribution pattern of plant assemblages would be more suitable: (1) sedge meadow, (2) *Scirpus validus* (tall emergent species that grew along the shoreline), (3) *Nuphar variegatum* and *Sparganium fluctuans* (both floating species growing in shallow to moderately deep water), (4) *Pontederia cordata* (short emergent species that grew in shallow water), and (5) open water without the presence of emergent or floating species. Note that we did not map the location of submergent species, because these were found growing below the water surface throughout the wetland, even where there were emergent and floating species. We verified that SAV was only absent in the vicinity of the opening to Twelve Mile Bay, where water depth approached 1.0 m. The second step was to locate homogenous areas (minimum size of 4 x 4 m) of each habitat class within the wetlands. Thirdly, we obtained geographic coordinates within each homogeneous patch for each of the five classes using a GPS unit. The number of geographical coordinates to be recorded could vary according to the habitat complexity and size of the wetlands. For instance, we collected 17 pairs of coordinates for SAV in Hay Bay 1 (ML1) while only two pairs of coordinates for the same class in Cove Island North Pond (CNP). This is because SAV in CNP was highly homogenous (i.e., CNP was almost 100% covered by SAV) and two points would be sufficient for us to select representative areas for SAV on the imagery.

(c) **Working with field data and satellite imagery in a remote sensing platform.** We imported the ground-truth data, along with the satellite imagery into a remote sensing platform using software called ENVI 4.1 (ITT Visual Information Solutions, formerly Research Systems, Inc., Boulder, CO). Then, representative areas, also called training areas, were identified within homogeneous areas for each habitat class on the imagery. The selection of appropriate training areas is generally based on the analyst's familiarity with the geographical area and the availability of ground truth data (Figure 3). In remote sensing, it is not unusual to have field and satellite data collected at different times for a variety of reasons (e.g., use of existing archive images, limited project budgets, timing of funding cycles, limited access to the field sites etc.). Since differences in vegetation cover between years may exist, the field data were not used directly in the classification procedure. Instead, field data were used to help the analyst to identify and choose representative areas of each habitat class on the imagery and then the representative areas were divided into a "training set" and a "testing set" to be used in a supervised classification procedure and to check for post-classification accuracy, respectively. For FFNMP wetlands, the training set was collected from Cover Island North

Figure 2. IKONOS images of Fathom Five wetlands and Herman's Bay.



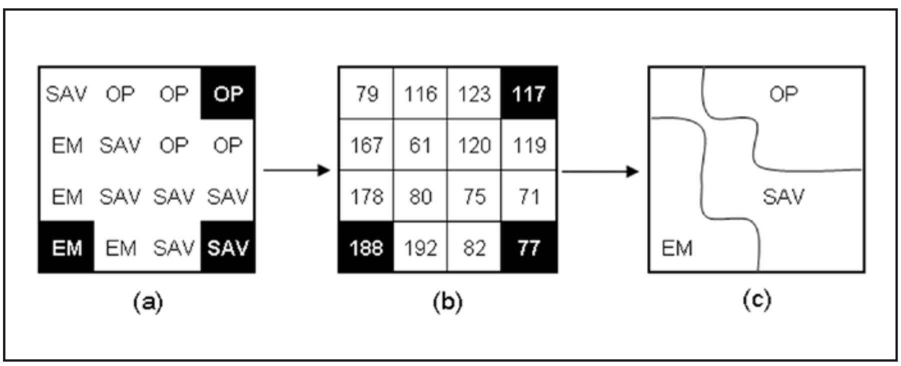
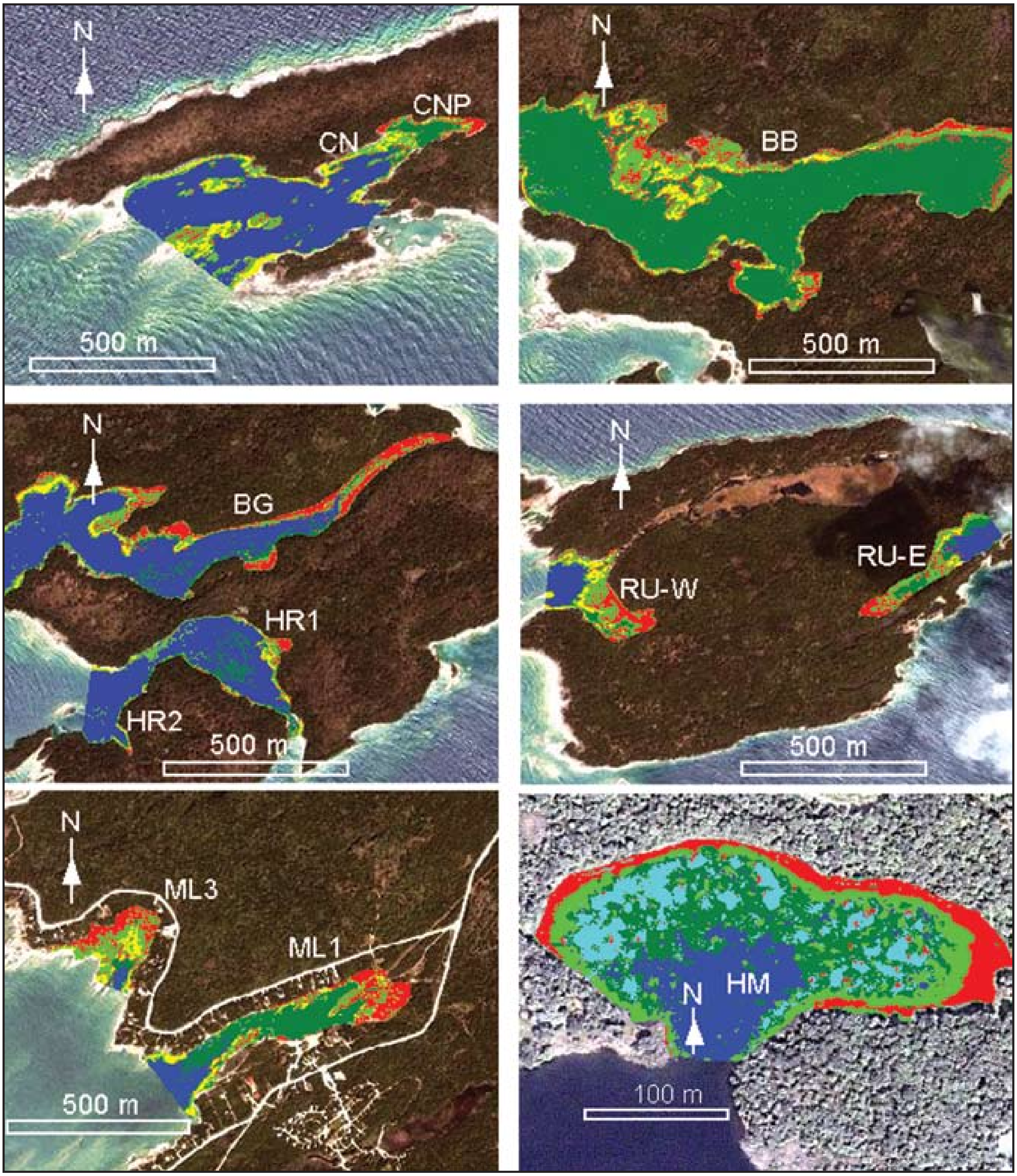


Figure 3. Supervised classification procedure for mapping wetland habitats.
(a) Three habitat classes in a hypothetical wetland. OP—open water, SAV—submergent vegetation, EM—emergent vegetation. Shaded areas are representative areas in the imagery identified by a human analyst with the aid of ground truth data (training areas).
(b) A digital representation of the imagery. Values represent the numerical "signatures" for each habitat class.
(c) Results of the supervised classification. Image pixels with similar numerical values will be grouped into the same habitat class.

Figure 4. Results of supervised classification.

Fathom Five wetlands:
red—emergent plants;
light green—rock/shrubs;
dark green—submergent plants;
yellow—rock;
blue—open water.

Herman's Bay:
red—sedge meadow;
light green—*Scirpus*;
dark green—*Nuphar* and *Sparganium*;
cyan (light blue)—*Pontederia*;
blue—open water.



(CN) and CNP while the testing set was independently chosen from ML1. The training and testing sets for Herman's Bay were collected from the west and east portions of the wetland, respectively.

(d) **Supervised classification procedure. with maximum likelihood algorithm** Our "supervised classification" procedure is commonly used in remote sensing. This procedure is applied in two steps (Lillesand and Kiefer 2000): (1) in the training stage, representative sample sites of known ground features (training areas), are provided to the classification algorithm (e.g., Maximum Likelihood) and form the basis for image classification; and (2) in the classification stage, the computer algorithm (e.g., Maximum Likelihood) categorizes each pixel in the image into the representative class it most closely resembles (Figure 3). To reduce the complexity of classification and computational time, we used the wetland boundary to delineate the "region of interest" to avoid processing areas in the satellite image that occurred outside the wetland.

(e) **Determining classification accuracy.** A classification error matrix is a common means of expressing classification accuracy. In such a matrix the accuracy values of each column indicate the percentages that are correctly classified. The overall accuracy reported in the classification error matrix is calculated by dividing the number of image pixels classified correctly by the total number of reference image pixels. Producer accuracy (Prod. Acc.) is calculated by dividing the number of correctly classified pixels for a class by the actual number of ground truth pixels for that class. User accuracy (User Acc.) is calculated by dividing the number of correctly classified pixels for a class by the total pixels assigned to that class.

RESULTS AND DISCUSSION

The 10 sites chosen from FFNMP for this study were all located within the same region of the satellite image. The goal of the Fathom Five study was to evaluate the capability of IKONOS imagery to accurately map aquatic habitat at a regional level. Results of the supervised classification for Fathom Five wetlands are shown in Table 2a and Figure 4. The classification error matrix based on the representative areas (testing set) indicated that the overall accuracy was 84.5% (Table 3).

During periods of high water, wetlands located on Cove Island were hydrologically connected to the rest of the lake, but during recent periods of low water levels (since 1999), some of these wetlands have become disconnected and "stranded." We found that these stranded wetlands had almost 100 % cover of submergent plants, and this is unlike other wetland areas of FFNMP that are exposed to wave action, where submergent plants are scarce.

Unlike wetlands of FFNMP, Herman's Bay is a highly protected marsh. It has a low-energy environment that allows organic matter to accumulate and thus supports a variety of aquatic plants in the marsh (Figure 2). The supervised classification estimated the following coverages for the five habitat features:

Table 2. Results of the supervised classification for wetlands in FFNMP and Herman's Bay. Data shown are calculated areas occupied by the various habitat features. See Table 1 for explanations of site codes.

(a) Fathom Five Wetlands

Site code	Submergent (m^2)	Emergent (m^2)	Rock (m^2)	Rock-Shrub (m^2)	Open water (m^2)
BG	11,712	25,264	6,112	25,808	98,896
HR1	7,648	3,120	1,600	7,536	36,688
HR2	944	480	720	3,520	23,712
CN	5,200	4,544	14,064	28,704	111,904
CNP	6,160	3,600	816	3,920	0
BB	262,912	40,336	18,784	66,832	1,792
ML1	30,656	15,824	5,616	13,984	11,536
ML3	2,112	10,784	5,120	12,528	1,760
RU-E	5,920	5,408	1,296	9,072	7,920
RU-W	2,432	8,672	4,896	12,896	9,568

(b) Herman's Bay

Parameter	Wet meadow	Open water	*Scirpus*	*Pontederia*	*Nurpha* and *Sparganium*
Area (m^2)	4,709	6,540	6,768	5,527	9,124
% Total area	14.4 %	20.0 %	20.7 %	16.9 %	27.9 %

Table 3 (a). Error matrix for Fathom Five wetland classification

	Training set		**Testing set**	
Class	Prod. Acc. (%)	User Acc. (%)	Prod. Acc. (%)	User Acc. (%)
Submergent	98.57	98.57	100.00	86.17
Emergent	96.15	89.29	58.33	100.00
Rock	93.33	82.35	NA	NA
Rock-Shrub	78.57	91.67	NA	NA
Open water	100.00	100.00	NA	NA
	Overall Accuracy = 97.28		% Overall Accuracy = 84.50%	

Table 3 (b). Error matrix for Herman's Bay classification

	Training set		**Testing set**	
Class	Prod. Acc. (%)	User Acc. (%)	Prod. Acc. (%)	User Acc. (%)
Meadow	99.54	100.00	98.08	100.00
Open water	99.75	98.50	100.00	94.59
Sedge	95.24	96.62	84.09	88.10
Nuphar	95.12	95.71	76.67	67.65
Pontederia	99.44	99.44	91.30	97.67
	Overall Accuracy = 98.19%		Overall Accuracy = 90.82%	

20.0% open water, 27.9% *Nuphar* and *Sparganium*, 16.9% *Pontederia*, 20.7% *Scirpus*, and 14.4% sedge meadow (Table 2b). The classification error matrix based on the representative areas (testing set) indicated that the overall accuracy was 90.82 % (Table 3).

Studies have shown that there is considerable improvement in the capabilities of IKONOS over Landsat and other satellite imagery that are more suitable for coarse habitat mapping (e.g., Andréfouët et al. 2005). Andréfouët et al. (2005) indicated that overall accuracy for Landsat was 15–20% lower than that for IKONOS when used to classify tropical coral reef environments, and that only IKONOS produced sufficiently high accuracy (> 80%) for four of the five classes. Our results indicate that IKONOS imagery can be used for wetland inventories, because of the large spatial coverage (over 100 km^2) and the relatively high level of precision when carried out with the supervised classification, both of which are required when gathering synoptic information at regional or basin-wide scales. On an areal basis, the cost of IKONOS images is substantially lower than that for aerial photographs, but still very expensive when compared with Landsat images (Table 4). If the primary objective of an investigation is to map the total wetland area for a large geographical area, Landsat will be more cost-effective. If habitat features need to be monitored at a small spatial scale (e.g., 100 m^2), and the area to be mapped is < 500 km^2, then IKONOS would be a cost-effective option (Mumby and Edwards 2002). Results from Herman's Bay also demonstrate that IKONOS imagery can be used to accurately identify plant form as well as species assemblages where training data are provided at the appropriate level of resolution (i.e., four broad groups with distinctive spectral properties). Our results indicate that use of IKONOS imagery to inventory wetlands has the advantage of wide spatial coverage and the precision of supervised classification, thus meeting the requirement for gathering synoptic information on wetlands at regional scales. The high water transparency and relatively undisturbed nature of the wetlands in eastern and northern Georgian Bay make them excellent candidates for use with IKONOS imagery for wetland classification.

Table 4. Cost-benefits of IKONOS, aerial photo, and Landsat satellite imagery

	IKONOS	Aerial photo	Landsat
Resolution	1m, 4m	variable	15m, 30m, 60m
Pricing*	\$2000/100 km^2	\$54000/100 km^2**	\$425 per scene (31,110 km^2)
Accuracy of seagrass mapping***	89%	63%	59%

* Pricing for basic level of products
**Pricing for aerial photo is reported in Canadian dollars
***Mumby and Edwards (2002) and Mumby et al. (1997)

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