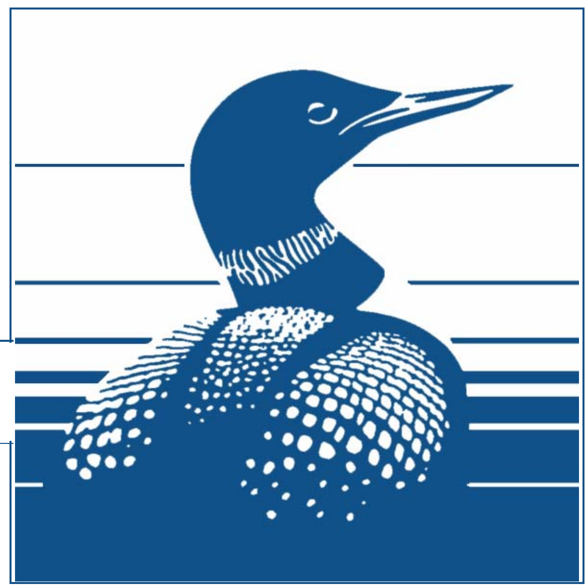
An evaluation of a methodology for wetland classification and inventory for Labrador

Matthew L. Mahoney, Alan R. Hanson and Scott Gilliland

Atlantic Region



Technical Report Series Number 480

Environment Canada / Environnement Canada
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AN EVALUATION OF A METHODOLOGY FOR WETLAND CLASSIFICATION AND INVENTORY FOR LABRADOR

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Canadian Wildlife Service Technical Report 480

This report may be cited as:

Mahoney, M.L., A.R. Hanson, and S. Gilliland. 2007. An evaluation of a methodology for wetland classification and inventory for Labrador. Technical Report Series No. 480. Canadian Wildlife Service, Atlantic Region. viii. + 40 pp.

Published by the authority of the
Minister of Environment
Canadian Wildlife Service

Catalogue number: CW69-5/480E-MRC

ISBN: 0-662-45481-6

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ABSTRACT

The objective for this project was to develop a methodology for classifying wetlands in Labrador with future applicability to a national Canadian Wetland Inventory (CWI). The study area was just east of Minipi Lake within the Eagle Plateau, and was dominated by peatlands within a coniferous forested landscape. Landsat-7 ETM+ and Radarsat-1 imagery was used to map wetlands at a minimum resolution of one hectare. An object-oriented automated approach with manual image-object refinement was used to classify wetlands as swamp, shallow water, fen, or bog. This study also developed a methodology for first classifying pan-sharpened Ikonos imagery and to use it for accuracy assessment purposes. Utilizing high-resolution imagery for accuracy assessment for an inventory is proposed as an alternative to more expensive helicopter field campaigns. Only calculating deterministic (absolute) accuracy was deemed insufficient because there is a gradual overlapping transition among different wetland types in Labrador, especially bog and fen. A fuzzy accuracy assessment was therefore also used in which misclassification within the peatland types was not considered an error. Using this fuzzy approach to validation, thematic accuracy was 79% compared to the deterministic accuracy of 57%.

RÉSUMÉ

L'objectif de ce projet était d'élaborer une méthodologie de classification des terres humides au Labrador pouvant être reproduite et s'appliquer dans l'avenir à un inventaire canadien des terres humides (ICTH) à l'échelle nationale. La zone d'étude était située à l'est du lac Minipi dans le secteur du plateau Eagle et était constituée principalement de tourbières dans une région peuplée de conifères. L'imagerie ETM+ de Landsat-7 et l'imagerie de Radarsat-1 ont été utilisées pour cartographier les terres humides à une résolution minimale de 1 hectare. Une approche automatisée axée sur les objets avec raffinement manuel des images-objets a été employée pour classifier les terres humides dans les catégories suivantes : marécage, eau peu profonde, marais et tourbière. Cette étude a également permis de développer une méthodologie visant la classification initiale de l'imagerie Ikonos à résolution panchromatique améliorée et l'utilisation de cette imagerie pour vérifier l'exactitude des données. L'utilisation d'une imagerie à haute résolution afin de vérifier l'exactitude des données serait très utile pour l'ICTH, car la validation des données et la formation sur le terrain ou par hélicoptère seraient très dispendieuses, étant donné l'immensité et l'éloignement du Nord canadien. Le calcul de l'exactitude déterministe (absolue) à lui seul a été jugé insuffisant, car la transition entre les différents types de terres humides au Labrador se fait par chevauchement graduel, en particulier en ce qui concerne les tourbières et les marais. On a donc procédé à une vérification floue de l'exactitude, où une classification erronée des types de terres humides n'était pas considérée comme une erreur. En utilisant cette approche floue de la validation, on a obtenu une exactitude thématique de 79 %, comparativement à l'exactitude déterministe, qui était de 57 %.

TABLE of CONTENTS

LIST of FIGURES

LIST of TABLES

INTRODUCTION

Wetlands serve a variety of ecosystem functions, including providing habitat for many species of fauna and flora, improving water quality, flood prevention, and sequestration of carbon (Bond et al 1992). Despite the recognized importance of wetlands, Canada does not have a national inventory that spatially quantifies the distribution and extent of wetlands. The Canadian Wetlands Inventory (CWI) is proposed by Environment Canada as a means to create a digital inventory of wetlands in Canada. Moving towards achieving this goal, the CWI has established a series of pilot study areas across Canada. In Atlantic Canada, one study site is just east of Minipi Lake in Labrador within the Taiga Shield's south-eastern fringe. The CWI program classifies wetlands (bog, fen, swamp, marsh and shallow water) based on the system developed by the National Wetlands Working Group (1997), at a minimum resolution of one hectare using an image-object approach. The vegetative and morphological breaks for the five classes are specifically defined in the National Hydro Network Data Model – Wetlands (Geobase, 2004).

This study had three objectives:

1. Use combined Landsat-7 ETM+ and Radarsat-1 imagery to develop a replicable image-object based methodology for classifying wetlands.

2. Develop an image-object based methodology for classifying the wetland classes using high-resolution Ikonos imagery.

3. Develop a methodology for using the classified Ikonos data to validate the combined Landsat/Radarsat classification.

Landsat and Radarsat imagery were the primary data sources for image classification. Approximately 20-25 Landsat images would be required to map Labrador, many also covering portions of northern Québec. Using Landsat imagery for this project was advantageous as data was readily available through Natural Resources Canada's cloud-free archive of images (Geobase, 2003), and its swath and resolution (180 km and 30 m) are a good combination for such a large spatial undertaking. Radarsat imagery alone has not proven sufficient in Labrador for distinguishing between different wetland vegetation cover-types and hence wetland types (Sokol et al., 2000), but given backscatter return differences from wet objects, it was hoped that synthetic aperture radar (SAR) would be useful for distinguishing between wetland and the upland fringe.

Previous large-scale studies have classified land-cover types including wetlands within the Minipi site such as Earth Observation for Sustainable Development (EOSD) (Wulder, 2002) and the Forest Resource of Labrador (Drieman, 1993). Neither of these previous studies were specific to wetlands.

STUDY AREA

The study site was approximately 50 km south of Happy Valley-Goose Bay, just east of Minipi Lake (Figure 1). The study area was 570,000 ha and situated at the south-eastern corner of the taiga-shield ecozone. It was dominated by coniferous forest, peatlands and woodland lichen with thicket swamps interspersed throughout. Given the proximity to the taiga/boreal boundary, it shares boreal characteristics including an extensive spruce and balsam fir forest.

Peatlands within the study area can extend up to 9.0 km across, but typically are 0.8 – 2.0 km in length. The two most common vegetation types are *Sphagnum* (moss) and *Carex* (sedge), albeit Labrador peatlands are floristically quite diverse (Foster and Glaser, 1986; Foster and King, 1984; Wells, 1996). Typically, brown and red *Sphagnum spp.* (*S. fuscum* and *S. rubellum*) grow within the more ombrotrophic environments, whereas *Carex spp.* are more prevalent in the more minerotrophic wetlands (i.e. fens).

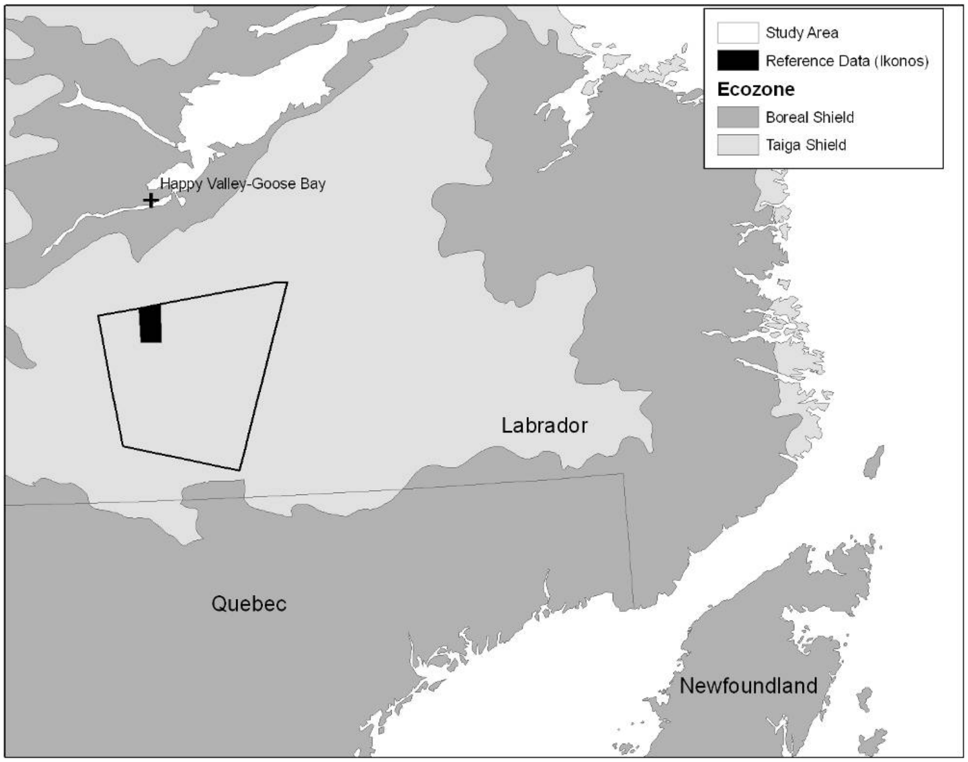

Figure 1: The Labrador Study Area

'Stringed' or 'ribbed' peatlands occur throughout the study area. These wetland types occur on sloping terrain with hummocks orientated perpendicular to the down-slope (National Wetlands Working Group, 1997). Separating bog from fen in the field can be problematic, with peatland complexes often having both bog and fen characteristics, e.g. raised ombrotrophic hummocks and minerotrophic vegetation growing within pools and along the upland edge (Wells, 1996; Wells and Hirvonen, 1988).

Marshes were not encountered within the Minipi study area, but are present in Labrador and consequently will be a wetland class to be addressed in the future. Other wetland types present in Labrador include basin marshes along Lake Melville (Lopoukhine et al., 1977); fluvial marshes in protected river valleys, and lakeshore marshes along the Smallwood Reservoir (Wells and Hirvonen, 1988).

DATA DESCRIPTION and PREPARATION

Landsat and Radarsat Imagery

Landsat imagery used in the study was collected, ortho-rectified and archived by the Centre for Topographic Information (CTI) (Geobase, 2003). The image used was path 08, row 23 and was captured on July 27, 1999 with minimal cloud cover. The late July image corresponded closely to the vegetative peak for the area. A standard-mode beam-7 Radarsat image acquired on May 19, 2000, was used in conjunction. PCI Geomatica™ software was used to pan-sharpen the Landsat image to 15 metre resolution and to filter the Radarsat image using a Touzi filter. A more detailed description of steps involved in pre-processing can be found in Mahoney and Hanson (2005).

Ikonos Imagery

The Institute for Environmental Monitoring and Research in Happy Valley-Goose Bay, Labrador, provided Environment Canada access to several pan-sharpened Ikonos images from Labrador. One image within the study area collected on July 12, 2004 was interpreted independently from the Landsat/Radarsat via an image-object based classifier. The preference would have been to have reference data from the same time as Landsat/Radarsat data, however, visual inspection on the overlapping areas revealed no new anthropogenic influences and most importantly, no sign of forest fires within the time gap. The classified Ikonos image was to be used exclusively for validation purposes.

Ground Confirmation

Field data was collected on 37 field sites on May 27, 2005. Although late May is not the optimum time to conduct a vegetative survey in southern Labrador, having a helicopter in the area for breeding waterfowl surveys made the data collection possible from a cost perspective. With a relatively small sample and a real need for proper image interpretation, it was decided to use all points for image training. Each site was visited for approximately five minutes, photographed, had its vegetation described in generalized terms (e.g. 30-40% balsam fir cover, extensive red *Sphagnum* under-story, with more *Carex* visible in wetter areas), and identified as one of the wetland classes or as non-wetland.

LABRADOR WETLAND DESCRIPTIONS

Bogs and fens

Labrador bogs are typically dominated by red and brown *Sphagnum* mosses (*Sphagnum rubellum* and *Sphagnum fuscum*), ericaceous shrubs (e.g. *Kalmia angustifolia*, *Chamaedaphne calyculata*), or reindeer lichens (*Cladonia spp.*) (Figure 2). Relative to bogs, Labrador fens generally contain more sedge (*Carex spp.*), *Myrica gale* (sweet gale) and less brown and red *Sphagnum* (Figure 3).

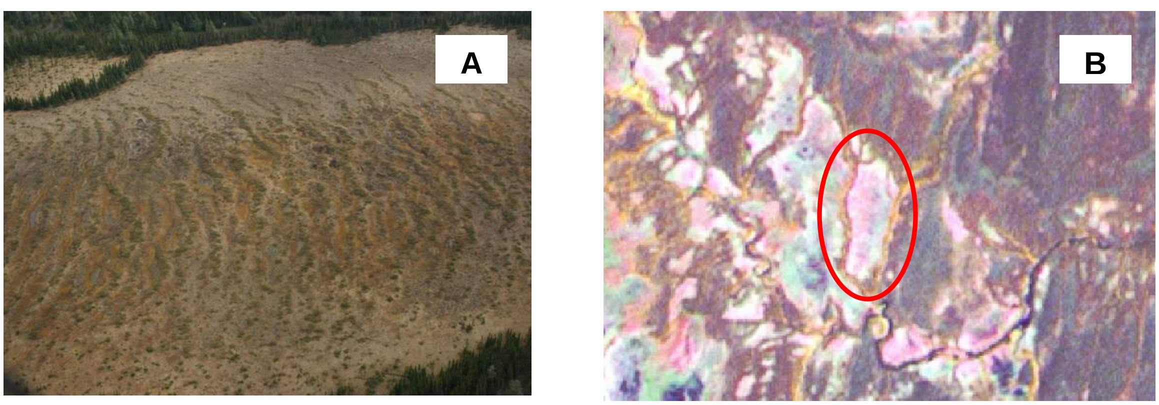

Figure 2 : Bog Wetland Class. Dry Bog with wet area in the centre (A). Extensive red Sphagnum (S. rubellum) cover. Corresponding area is shown on a Landsat 4-5-3 composite (B).

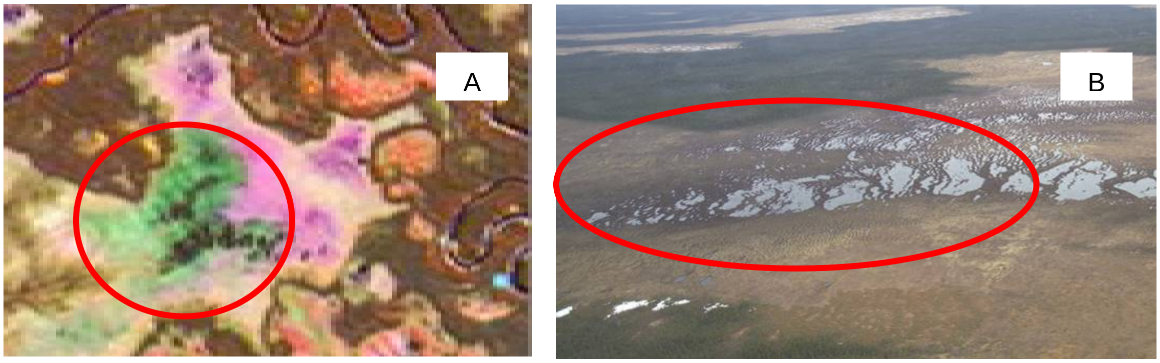

Figure 3: Fen Wetland Class. Green tone on 4-5-3 composite (A) indicates rich fen, dominated by Carex. The corresponding area is represented on the oblique (B).

Labrador peatlands, particularly string peatlands, can be heterogeneous in nature. In an object-oriented classification it is not uncommon for one polygon to contain *Carex*, *Sphagnum*, lichen, and water elements. Labrador peatlands are unique in that they can have poor fen and shallow pools covering up to 60-80% of the surface area, with the remainder covered by raised hummocks dominated by bog species (Wells, 1996; Wells and Hirvonen, 1988). This makes assigning the entire wetland-complex to one wetland class difficult from both ecological and from satellite image interpretation perspectives.

Swamp

Swamps were dominated by alder and willow shrubs that can typically be found growing adjacent to river and stream beds (Figure 4). Coniferous swamps are not common in Labrador. Distinguishing between deciduous swamp and deciduous upland on Landsat/Radarsat imagery can be difficult. Deciduous vegetation such as poplar and birch, are amongst the first trees to re-colonize in areas where forest fire has occurred. Spectrally, regenerating vegetation at this stage appears similar to the riverine alder and willow shrub composing the swamp class. Careful consideration of the effects fire has upon the landscape is an important factor in wetland classification.

Shallow Water - Aquatic Vegetation

This class tended to consist of emergent aquatic vegetation growing within a larger water-body. Open shallow water covers 75% of the surface area. Unfortunately it was absent on the Ikonos image used for validation, but an example was found on another high-resolution image outside the study (Figure 5).

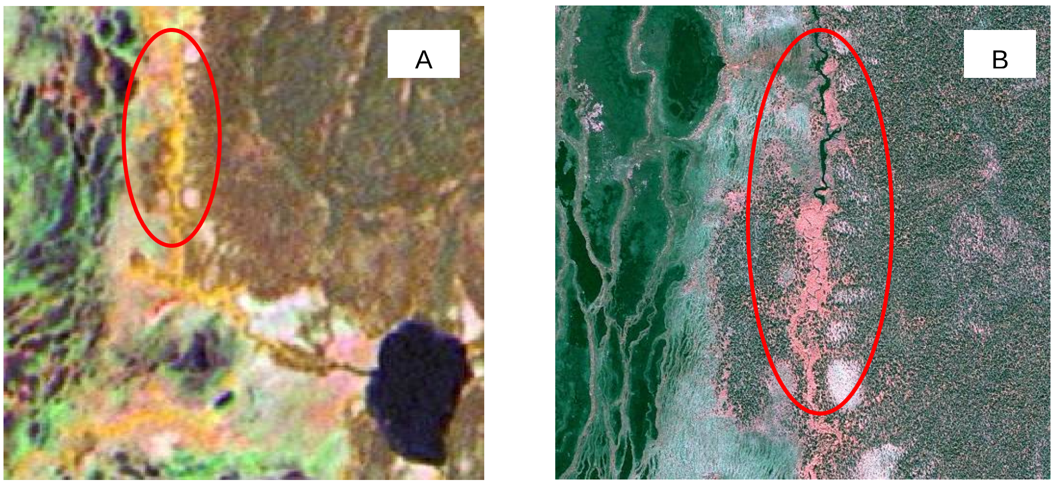

Figure 4: Swamp wetland class dominated by deciduous shrubby vegetation. (A) is a Landsat 4-5-3 composite, (B) is an Ikonos 4-3-2 false-colour composite.

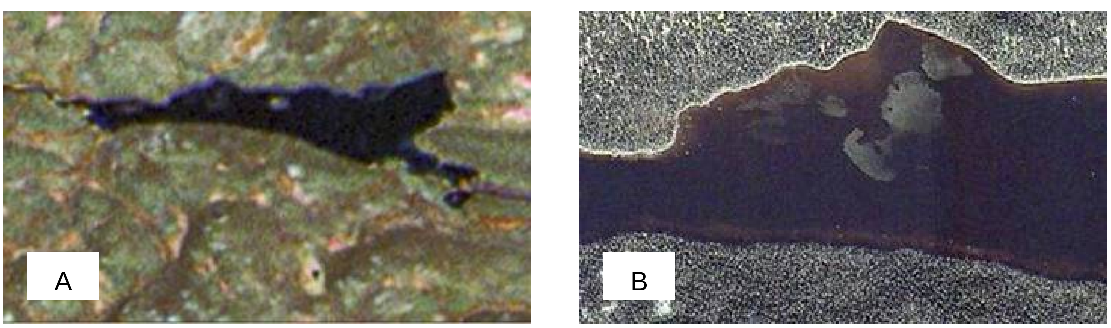

Figure 5: Shallow water wetland class, emergent graminoid vegetation.

METHODOLOGY

Landsat/Radarsat Image Segmentation

Considering that an objective of this study was to devise a methodology for classifying wetlands within the eastern taiga-shield, it was important to develop a repeatable methodology. Furthermore it was necessary to closely document strategies deployed for identifying wetland classes in addition to those used for removing all non-wetland classes.

Segmentation and classification was performed using eCognition™ v. 4.0.6 object-oriented image analysis software. Of the five parameters that can be adjusted affecting how image-objects are generated scale parameter (SP) is the most significant for determining image object size and vegetative homogeneity (Sohlbach and Benz, 2004). SP was the only variable adjusted during trials for the medium resolution imagery. Segmentation was executed on five levels, however, the majority of wetland image objects were classified directly on one level with average image-object area equal to 2.1 ha. The major exception was the swamp wetland class which was targeted at a finer level with average image object size equal to 0.64 ha (and later aggregated to meet the 1.0 ha minimum mapping unit).

Landsat/Radarsat Classification

Classification was executed on multiple levels in a hierarchical manner within eCognition (Figure 6). The general classification philosophy was to identify the target class and then eliminate all that is not the target. The software was used to set rigid spectral boundaries for each class, for example in order to be considered bog, NDVI (normalized differential vegetation index) might have had to be between 0 and 0.4. Common spectral properties utilized included means, ratios, NDVI, NDWI (normalized differential water index) and the three tasseled cap transformations for Landsat ETM+: brightness, greenness and wetness (Crist and Cicone, 1984). Manual refinement was performed as required. Classified wetland image-objects were exported as a GIS layer and those less than 1 ha adjoining wetland objects were dissolved into one another (Figure 7).

Level 5 (average image object size: 85.8 ha)

This level removed image objects where forest fire was evident and pure *Cladonia* lichen non-wetland areas. Forest fires rarely consume everything in their path and as a result the vegetation left behind varies, as does the resulting spectral signature (Kachmar and Sánchez-Azofeifa, 2006). Considering the variance amongst forest fire signatures, it was easier to manually and rapidly identify large objects.

Level 4 (average image object size: 12.8 ha)

The primary objective at Level 4 was to target the conifer-lichen upland class. Once the target's definition was ensured, further refinement of the Landsat/Radarsat classification was able to identify the spectral properties necessary for its separation.

Level 3 (average image object size: 2.1 ha)

Most wetland image objects were first recognized at Level 3. The majority of peatland complexes were first identified and at subsequent levels separated into bog and fen. The wetland's wetter portions (ponds) tended to have different reflectance values or backscatter return than the drier more vegetated components. This precluded using an all-encompassing feature for classifying peatlands. Ponds were first identified and then grouped back with a wetland class further down the hierarchy. Additionally, wetlands known to be fens or bogs were fully separated at Level 3.

Level 2 (average image object size: 2.1 ha)

Level 2 was created to further eliminate image objects that were incorrectly identified as being ‘peatland-water’. Image-object size was the same as at Level 3. Peatland-water objects that did not border any (vegetated) peatland objects were excluded from consideration as wetland. Objects that border more fen than bog were considered fen and vice versa.

Level 1 (average image object size: 0.64 ha)

Swamp was targeted for the first and only time in the classification at Level 1, regardless how the object was classed at higher levels. Swamps mainly grew as swales that tended to develop in narrow bands along small creeks and major rivers that necessitated a fine scale parameter in eCognition to delineate. Shallow water was also targeted at this level.

Ikonos Segmentation

Ikonos segmentation occurred on two levels and was also executed with eCognition software. Initially the procedure replicated the Landsat/Radarsat procedure by only altering the *scale parameter*. This approach generated image-objects that did not replicate a natural wetland’s shape. Increasing the *shape* parameter’s weight had the desirable effect to produce more natural image-objects.

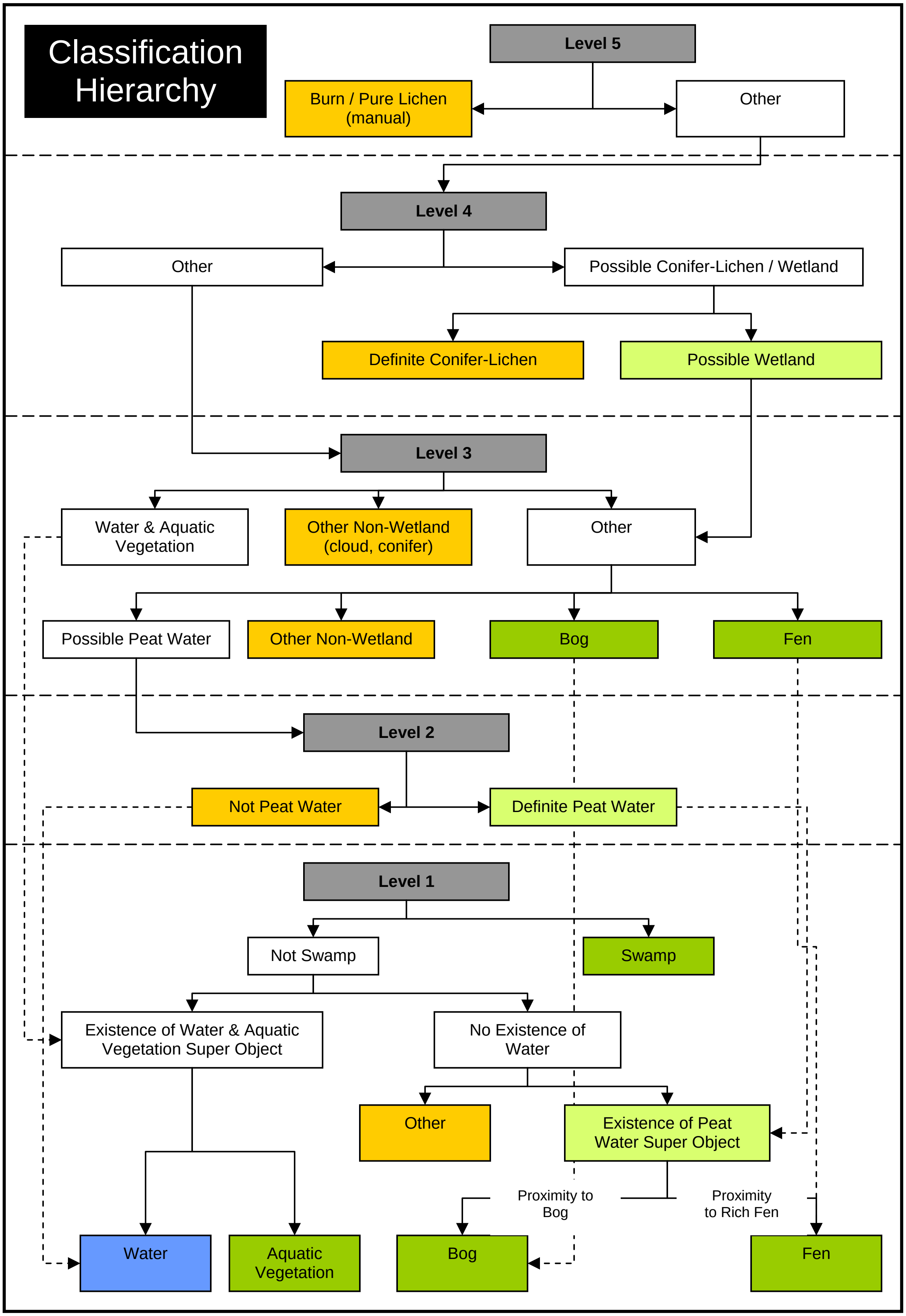

Figure 6: Landsat/Radarsat Classification Hierarchy**.**

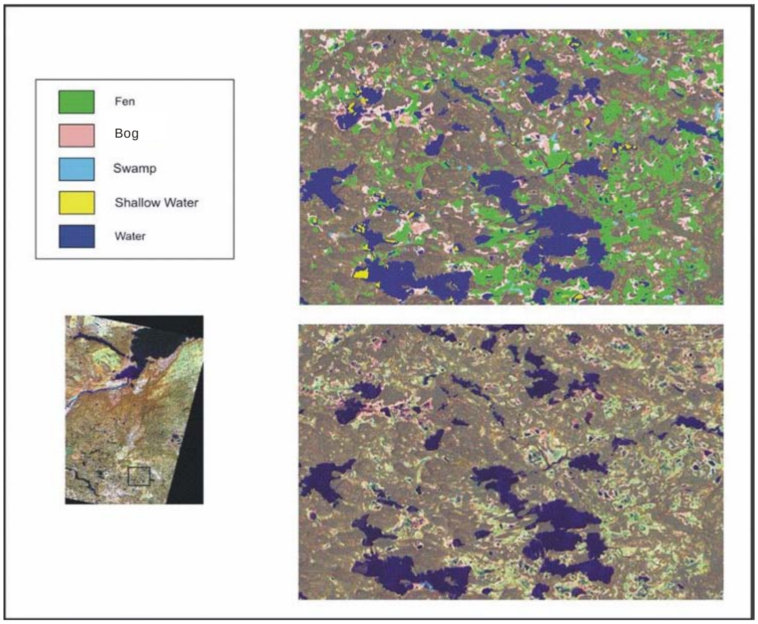

Figure 7: Combined Landsat/Radarsat Classification

Ikonos Classification

The procedure to classify the Ikonos imagery was simpler than the Landsat/Radarsat classification (Figure 8). Only two levels were used in the hierarchy, one with average image object size equal to 3.4 ha, the other 0.41 ha. Spectral features used to separate classes included NDVI, means and ratios. Additionally, manual classification was performed as required. Peatland image objects that could be identified at the higher level were classified, if not they were classified at the lower level. Swamps were classified exclusively at the lower level. A peatland-water class was also targeted at level 1 and later re-classified at as being either bog or fen based on proximity and the length of the bordering wetland type. There were no shallow water wetlands visible on the imagery. After the image was classified it was compared to seven field sites observed in June, 2005, all were classified correctly (Figure 9).

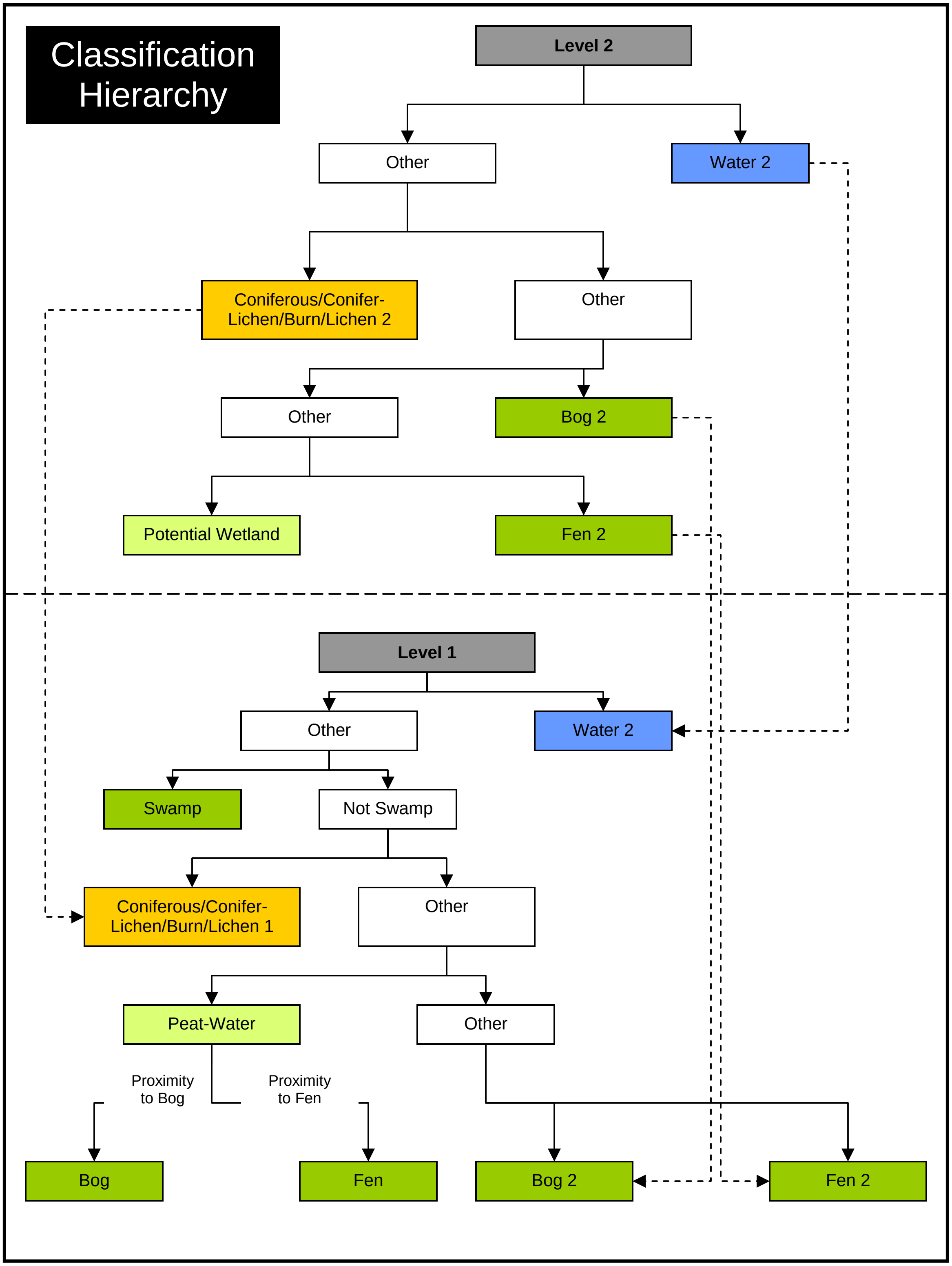

Figure 8: Ikonos classification hierarchy

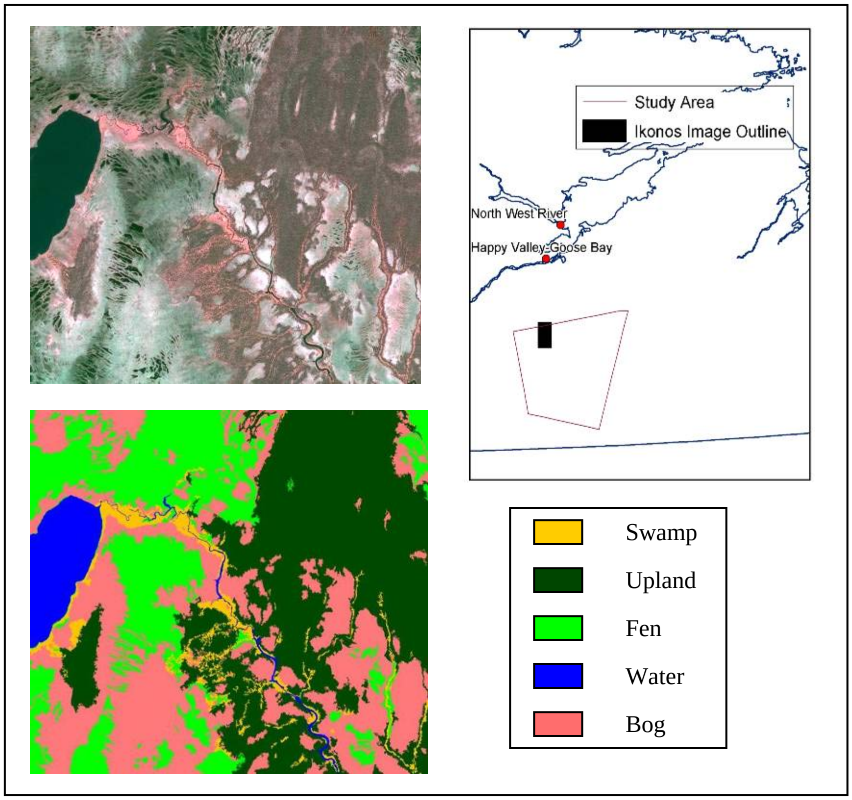

Figure 9: the Ikonos Classification

RESULTS/DISCUSSION

Accuracy Assessment

Thematic accuracy for the Landsat/Radarsat classification was assessed relative to the classified Ikonos imagery in both a discrete (traditional) and a fuzzy manner. The deterministic accuracy assessment was strictly a binary process whereby a site classified as bog was correct if it was also classified as bog on the Ikonos reference classification. The marsh and the shallow water wetland classes were both absent from the Ikonos study area, leaving only three wetland classes in the accuracy assessment: bog, fen and swamp. Within the study area the main wetland types classified were bog and fen, each covered approximately 10% of the study area. Swamps covered just over 2% with the remaining area being non-wetland.

Accuracy can be calculated three different ways in an error matrix: producer's accuracy, user's accuracy and overall accuracy. Producer's accuracy is the probability that a reference polygon is correctly classified, otherwise referred to as omission error. Producer's accuracy for individual classes can be calculated by looking at the individual rows in an error matrix (e.g. 63 reference bog polygons/100 = 63%). In contrast, user's accuracy is the number of correct samples in a category divided by the total samples for the category, also referred to as commission error and devised by examining the columns in an error matrix (e.g. for swamp 15/17 = 88.2%). Overall accuracy is simply accuracy for all classes and can be calculated by dividing sum of all the diagonal values in the matrix by the total number of classes.

Thematic sample selection was randomly stratified by class. Congalton and Green (1999) recommend at least 50 samples from each land-cover class be used in an error matrix, which is used to determine the overall and individual class accuracy for a classification (Jensen, 2005). Given the swamp class was the least abundant it was decided to use 50 swamp samples, and considering bog and fen were more prevalent there would be more peatland samples. One hundred samples were collected for the bog class and 64 for the fen class. Even though fen covered roughly the same area as bog, numerically there was only approximately 2/3 as many fen polygons. It was also important to consider the non-wetland class within the error matrix in order to ensure that wetlands were being identified. Fifty random non-wetland samples were collected, consistent with the minimum recommended number for an error matrix. Considering that 78% of the study area was non-wetland, the chances for any random pixel being non-wetland was also 78%; therefore too many samples would skew the results in a positive direction. A sample was considered correct if the polygon's centroid (or label point) was the same as on the classified Ikonos image (Table 1).

Given the vegetative and morphological similarities between Labrador bogs and fens (Wells, 1996; Wells and Hirvonen, 1988), it was considered reasonable for the two to be misclassified as each other on medium resolution Landsat/Radarsat imagery. It was also considered acceptable for a bog to be classified as a swamp and vice-versa, given the varying amount of tree cover that can occur on bogs. An error matrix was employed allowing for both deterministic and fuzzy accuracy (Green and Congalton, 2003; Grenier et al., 2005). The diagonals in the matrix represent those sites correctly classified according to a traditional error matrix (deterministic). The off-diagonals contain two numbers (X_1, X_2). X_1 represents samples that were classified differently on the reference data, but the difference was acceptable according to the fuzzy rules. For example bog classified as fen or fen classified as bog. X_2 represents samples that are wrong by any definition, e.g. bog classified as non-wetland.

Table 1: Thematic Fuzzy Classification Error Matrix

					Producer's Accuracy			
Class	**Bog**	**Fen**	**Upland**	**Swamp**	**Deterministic Totals**	**Deterministic Percent**	**Fuzzy Totals**	**Fuzzy Percent**
Bog	63	20,0	0,16	1,0	63/100	63%	84/100	84%
Fen	24,0	23	0,16	0,1	23/64	35.9%	47/64	73.4%
Upland	0,0	0,0	50	0,0	50/50	100%	50/50	100%
Swamp	12,0	0,4	0,19	15	15/50	30%	27/50	54%

User's Accuracies

Deterministic Totals	63/99	23/47	50/101	15/17
Deterministic Percent	63.6%	48.9%	49.5%	88.2%
Fuzzy Totals	99/99	43/47	50/101	16/17
Fuzzy Percent	100%	91.5%	49.5%	94.1%

OVERALL ACCURACIES

Deterministic		**Fuzzy**	
151/264	57.2%	208/264	78.8%

Kappa statistic (fuzzy) = 0.71

Discussion

Combined Landsat-7 and standard mode Radarsat-1 imagery provides a mechanism for mapping wetlands in northern Canada. Overall deterministic accuracy was 57.2% and was calculated by summing the diagonal in the error matrix (table 1) and dividing the total by the number of samples (151/264). Overall fuzzy accuracy was 78.8% (208/264). The kappa index of agreement (KHAT) statistic was calculated for the fuzzy classification and was equal to 0.71.

The deterministic user's accuracy for the bog class was 63% (63/100), while the fuzzy user's accuracy was 84% (84/100). The difference between deterministic and fuzzy being made up almost entirely by bog being classified as fen. Fen classification was less accurate, deterministic producer's accuracy was 35.9%, with fuzzy accuracy improving to 73.4%, a significant enough difference to suggest fen is overestimated. For bog, fen and swamp producer's accuracies are all above 90%.

The non-wetland class had user's accuracy (commission error) equal to 100%, whereas producer's accuracy was only 49.5%, suggesting areas classified as wetland are actually non-wetland. Of the 51 non-wetland sites improperly classified as wetland, 19 were swamp (37.3%). Considering the relatively small proportion of the study area that was swamp (approximately 2%), the commission error may be over-estimated slightly but it is still significant.

One advantage of mapping in the north is that on many Landsat scenes there is little or negligible anthropogenic influences on wetlands more commonly observed at southern latitudes. Decisions regarding how to classify peatlands drained for commercial peat extraction, or conversion of wetland to agriculture are not issues. That is not to say that the north is without disturbance. Fire causes significant problems in satellite image interpretation, converting swamps and peatlands to barrens. Regarding swamp classification, it was difficult to distinguish between re-colonizing deciduous vegetation and the deciduous vegetation one would expect in a treed or shrub swamp, which partially explains the high errors of commission due to non-wetland areas being classes as swamp.

The largest challenge remaining for understanding Labrador wetlands is to completely separate bog from fen. Similarities between vegetation species present in both peatland types makes it challenging to separate the two from one another, particularly considering that it is not unusual for a single peatland to contain portions that are both ombrotrophic (bog) and minerotrophic (fen). It is expected that complete separation will be difficult to attain due to the nature of Labrador peatlands and the resolution of the Landsat and Radarsat satellites.

ACKNOWLEDGEMENTS

Thanks to Dr. Louis LaPierre with IEMR who agreed to make high-resolution imagery available for the project, to Tony Parr, also with IEMR, for his assistance in providing data files. Frances MacKinnon with the Nova Scotia Department of Natural Resources who was kind enough to help with the GIS procedures. Lastly the Canadian Space Agency is acknowledged for supporting the Canadian Wetlands Inventory Project.

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