Modeling land cover dynamics to assess the sustainability of wetland services: a case study of the Grand Lake Meadows, Canada

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Abstract. The Grand Lake Meadows is an important part of the Saint John River wetlands that form the largest freshwater wetland habitat in the Maritimes (eastern Canada). Changes in the land cover and use around wetlands significantly impact their biotic diversity, alter the ecosystem, and affect their ability to support human needs. The goal for this paper was to undertake a detailed and spatially explicit inventory of local trends in land use and land cover changes in Grand Lake Meadows over a 20-year time period. This goal was achieved through classifying historical remotely-sensed images to map the state of land use and cover. Other available data were combined with this information to create a database that was used to investigate the causes and consequences of changes. The results demonstrated the flexibility and the effectiveness of this technology in establishing the necessary baseline and support information for sustaining the eco-services of a wetland. The study identified a 38% decrease in the wetland from 1990 to 2001, while there was 80% increase in the wetland area since then. The result will help managers to comprehend the dynamics of the changes, prompting a better management and implementation of LULC administration in the area.

Key words: Remote Sensing, Land Cover Mapping, Wetlands.

1. Background
Extensive loss of wetlands has occurred in many countries throughout the world (Ozesmi and Bauer, 2002). A recent study found that the world’s wetlands have declined by 6% between 1993 and 2007, largely due to human development (Tiner, 2015). Growing environmental awareness combined with increasing appreciation of the environmental services and the ecological significance of wetlands have resulted in recognizing the importance and the urgency of protecting and conserving these ecosystems (Al-Tahir and Baban, 2005).

Changes in the land cover and land use significantly affect key aspects of ecosystem functioning and services of wetlands. Thus, it is important to inventory and monitor wetlands and their adjacent uplands to conserve the existing wetland ecosystems (Ozesmi and Bauer, 2002; Tiner, 2015). This situation has created a need for mapping and monitoring spatial and temporal changes in ecosystems, and providing consistent and objective methods for decision making (Al-Tahir and Baban, 2005).

Grand Lake Meadows (GLM) is the largest fresh water wetland in New Brunswick. The area is classified as a Protected Natural Area due to its historical and ecological significance to the province of New Brunswick. The area is home to a number of species of diverse and significant plant communities and can be counted as one of the unique treasures of Canada’s natural heritage (Washburn and Gills, 1996). GLM provides several ecosystem services that a wetland would typically
provide, such as carbon storage, timber production, water-quality improvement, and sediment retention. It also provides several economic services that include recreation (bird watching, boating, cross country skiing, duck hunting, and snowmobiling), beef cattle operation, crop production (cabbage, pumpkins, corn, tomatoes, and potatoes), and harvesting (firewood, fiddleheads, and muskrats) (Washburn and Gills, 1996).

Historical maps of the region and data from the Canadian census depict changes in the demographic aspects and trends in the GLM area. The maps also show changes in the land cover and use of the area, particularly a considerable amount of highways and settlements. One specific observation is that cultivation activities decreased significantly from 1901-2001, as noted by the acreage of Hay, Buckwheat and Oats (Paponnet-Cantat and Black, 2003), primarily due to construction in Gagetown and people’s movement from a rural area to an urban area.

The Trans-Canada highway was proposed to be re-routed in the early 1990s. Washburn and Gillis (1996) were responsible for a preliminary environmental impact assessment. They defined the area of GLM as being bounded on the east by the Jemseg River, and to the north by various bodies of water including Grand Lake, Back Lake, Maquapit Lake, French Lake, and two extensive thoroughfares. The southern extent of the GLM area is bound by the Saint John River, while the western limit is a road that connects McGowans Corner to Lakeville Corner (Washburn & Gillis, 1996; Paponnet-Cantat and Black, 2003). Figure 1 illustrates the location of the Grand Lake Meadow area within New Brunswick, and that of New Brunswick within Canada.

![Figure 1](image)

**Figure 1.** Location of the Grand Lake Meadows in New Brunswick, Canada.

The main goal for this study is to assess the state of the GLM landscape through mapping the land use land cover over the years using satellite images, and identify how the landscape of GLM has changed over the years. This study attempts also to assess if there is a relationship between the landscape changes with other physical or policy changes.

2. Methodology
The methodology’s main thrust is the use of a series of archival satellite images covering a period from the years 1992 till as recently as 2013. Comprehensive land cover maps for the Grand Lake Meadows area were extracted from these images and then analyzed to depict changes in land cover. A specific set of indicators were selected based on being easily extracted and updated, directly or
indirectly, using geo-imaging techniques. Of special interest is assessing the ecological impacts of the Trans-Canada Highway on the GLM area.

GIS is used in this study to enable the integration and presentation of the spatial and temporal information. Additionally, it allows for conducting a series of spatial and geo-statistical analyses to quantify the rate of changes and the association between different parameters. Figure 2 is a flow chart depicting the process to achieve the aim of analyzing the state of degradation in the GLM region.

**Figure 2.** Data and processes flow.

### 2.1 Datasets
The images used for this study were all Landsat imagery with world reference system 10/28 from [http://earthexplorer.usgs.gov/](http://earthexplorer.usgs.gov/) covering the study area dating 1992 till 2013. Table 1 lists the images used in this study. These images included, at least, images from four spectral bands (blue, green, red, and near-infrared) with a resolution of 30m. All the images used in this study were of the same time of the year, to negate the effects of seasonal variations. Additionally, all images used in this study had a cloud threshold value of less than 10% to minimize the effects of cloud cover.

**Table 1.** Satellite images used in the study

| Date       | Satellite | Spectral Bands                  | Resolution          |
|------------|-----------|---------------------------------|---------------------|
| 1992/08/07 | Landsat 5 | 4: B, G, R, IR                  | All bands: 30m      |
| 2001/06/28 | Landsat 7 | 7: B, G, R, NIR, SWIR1, TIR, SWIR2, Pan | VIR: 30m, TIR: 60m  |
| 2013/08/24 | Landsat 8 | 11: B, G, R, NIR, SWIR1, TIR, SWIR2, Pan, TIRS, Cirrus | VIR: 30m, Pan: 15m, Cirrus: 30m, TIRS: 100m |

Two other datasets were used for this study: Forestry maps and the road network. Forestry maps were acquired from the Department of Natural Resources to provide training and validation samples for the classification of the satellite images. These maps are of 1:12,500 scale and bear the numbers 4852, 4952 and 5053 and represent the study area in 2014. The road network dataset for 2013 (downloaded from [http://www.snb.ca/geonb1/e/DC/catalogue-E.asp](http://www.snb.ca/geonb1/e/DC/catalogue-E.asp)) is a shapefile of 1:15000 scale.

### 2.2 Pre-processing
The satellite images were geo-referenced to the New Brunswick coordinate reference system and map projection (NAD83 CSRS 19N, New Brunswick Stereographic Double projection). An ortho-image for the area downloaded from GeoNB was used for selecting ground control points. To ensure consistent referencing between the images, the same ground control points were used on all the images classified. However, this could not be completely done for all the points due to the changes of the satellite images over the stated time period. The RMSE for the geo-referenced imageries was less than 0.25 of a pixel (about 8m) based on selected ground control points.
The 2013 road network was then modified (backdated) using the satellite images to represent the road network at the different time frames corresponding to the dates of satellite images. The backdated road information was later super-imposed over the classified images.

3. Extracting land cover information from satellite images

3.1. Developing a classification scheme

Prior to extracting land cover information from satellite images, we first developed a classification scheme. The categories for land cover classes used in this study followed the Anderson Classification system and derived from the Forestry maps. The original legend for the Forestry maps has an extensive list of categories for various types of forest species and vegetation covers. Those classes were modified to aid the objectives for this study. Accordingly, the adopted classification scheme comprises the six classes, as listed in Table 2.

| Category         | Description                                |
|------------------|--------------------------------------------|
| Water            | Streams, river, lakes and other water bodies|
| Submerged Wetland| Wetland that is seasonally flooded with water|
| Wetland          | Land saturated with water                  |
| Non-forest       | Combines non-forest land, partial cuts, burns and cutovers |
| Forest           | Includes all the different categories and forest types |
| Roads            | Includes all the different types and categories of roads |

3.2. Image classification

This study used eCognition software (by Definiens Imaging GmbH) to perform object-oriented classification. Segmentation is the fundamental step in the object-based image analysis by eCognition. This step subdivides the image scene into separate unclassified image object primitives. These objects can then be classified to get both a meaning and a label (Definiens, 2007). The multi-resolution segmentation algorithm is one of the highly sophisticated approaches provided by eCognition to minimize average heterogeneity and maximize homogeneity within image object primitives. The homogeneity criterion is defined by a combination of spectral color and shape properties of image objects. It is controlled by modifying a scale parameter: higher values for the scale parameter result in larger image objects, smaller values in smaller image objects (Definiens, 2007).

To get the best segmentation results, the scale parameter was set as 185 in this study. This value was achieved through several trials, because there is no specific rule for choosing a certain value scale parameter. The segmentation step was repeated with varying scale parameter until an optimum result was achieved.

The next step was image classification, where this study used the Support Vector Machine (SVM) algorithm in eCognition. The Support Vector Machine is a superior machine-learning methodology with great results in pattern recognition, especially for supervised classification of satellite images (Tzotsos and Argialas, 2008). This algorithm analyzes data and recognizes patterns by taking a group of input data and predicting, for every given input, which of two possible classes the input could be a member of (Definiens, 2007).

Training sample areas required for the supervised classification were extracted from the relevant Forestry maps, and spectral signatures were created accordingly. The results of applying the classification algorithm on each of the satellite images are depicted in figures 3, 4, and 5 for the years 1992, 2001, and 2013, respectively.
Figure 3. LULC classification results for 1992.

Figure 4. LULC classification results for 2001.

Figure 5. LULC classification results for 2013.
3.3. Accuracy assessment

To evaluate the accuracy of an image classification, it is a regular practice to create a confusion matrix, by which results are contrasted with reference data. Surrogates to ground truths were obtained from the existing land cover data (Forestry maps). The set of samples used for accuracy assessment differs from that of the training samples. However, the same test area samples were used in all the images to get the classification accuracy of each image to maintain consistency. The overall accuracies of 84% for 2013, 85% for 2001, and 82% for 1992 obtained from the classification were quite close to each other. Table 3 shows the producer accuracy exclusively for the combined land cover class of wetland and submerged wetland in the three different dates.

| Year | %  |
|------|----|
| 2013 | 67 |
| 2001 | 75 |
| 1992 | 63 |

As can be seen, the wetland and submerged wetland accuracy in the three images are slightly different due to the fact that the wetland and submerged wetland are affected by weather conditions, especially rainfall in the period prior to the imaging.

4. Results and analysis of land use changes

The areas of all land use categories in the three time frames were extracted as shown in Table 4. Since the focus of this study is assessing changes to wetland against other classes, Table 4 shows four classes instead of the original six classes. Accordingly, Forest and Non-forest (including bare land and vegetation such as shrubs, orchards) land cover types were grouped as one class. Similarly, wetland and submerged wetland classes were also grouped as one class. The change in land use was calculated by subtracting the areas of land uses in 1992 from those of 2001, and 2001 from those of 2013.

| Land Cover Type | 1992 | 2001 | Change (ha) | 2013 | Change (ha) |
|-----------------|------|------|-------------|------|-------------|
| Roads           | 1597 | 3.36 | 2196        | 4.63 | 599         |
| Water           | 9202 | 19.41| 9420        | 19.88| 218         |
| Forest+Non-forest| 26076| 55.03| 29227 | 61.67| 3151        |
| Wetland         | 10517| 22.2 | 6549 | 13.82| -3968       |

While Table 4 shows that there was a steady increase in area of roads from 1992-2013, roads occupy only a small percentage of the total area of GLM. Water body area increased by 2.36% from 1992 to 2001, but there was a decline of about 1.42% from 2001-2013. This may be attributed to seasonal or annual variation of rainfall or snow melting. In both of these cover classes, the numbers do not represent a major change in area that can cause an impact on the ecology.

There was an increase of 12% in the forest and non-forest from 1992-2001. This may be attributed to the declaration of the GLM area in the 1990’s as a "Class 2 Protected Natural area" which in-turn limits the utilization of the territory to low-impact recreational activities and conventional sustenance gathering activities, while limiting industrial, business and horticultural improvements. In the year 2001-2013 there has been a depletion of about 7% in forest and non-forest (deforestation). This could be the result of increased human activities associated with the nearby area of Gagetown (a military base). Incidentally, it is only in the second half of this period that the crown land management plan was enacted (in 2007) that reduced the annual allowable cut (AAC) of the hardwood from 1.77 million
cubic metres to 1.41 million cubic metres. This reduction would ensure a sustainable hardwood supply in the future.

Lastly, the results show a decrease in the area of wetland class (including the submerged wetland) from 1992-2001 of about 38%, but an increase of 68% from 2001-2013. This adds up to a 4.32% overall increase in the wetland area in the GLM area. One must be careful in interpolating this information regarding wetland area, as well as the area of water, without considering annual variations in rainfall, temperature, and snow melting for these specific years.

5. Conclusion

Wetland habitats are important for maintaining and preserving healthy ecosystems. However, wetlands are under pressure due to human activities, economic development, and climatic processes. Sustainability of the wetland services can be achieved through careful planning and management, both of which demand up-to-date maps of the spatial distribution of land use and cover, the history of evolution of the ecological landscape, as well as the characterization of the region in terms of the ecological, economic, and environmental value of the wetland.

Within this context, this study was successful in developing a methodology to monitor and measure changes in land use and land cover for Grand Lake Meadows (New Brunswick, Canada) over a period of 21 years. The study also developed a land cover classification scheme that incorporated the land cover scheme used by the Forestry maps, and followed the Anderson Classification System.

The land cover/use maps produced for each date reflected and aided in modelling how the landscape of GLM has changed over the several years. Thus, the methodology developed in this paper can offer a quantitative tool to help achieve sustainability of wetland services, by providing the information basis to better manage and use the resources in the Grand Lake Meadows. By employing time-series information, it may be possible to predict trends in land use change. This would provide the managers of the GLM with alternatives for the best way to maintain this protected area. Additionally, the developed methodology provides for continuous environmental monitoring of the GLM, which is important for evaluating the effectiveness of the implemented management strategies.

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