Impact of Landuse Practices on Ecosystem Diversity using Remotely Sensed Data

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Abstract
Owing to the concerns over the increased emissions of GHGs significant efforts are being made in Canada to produce fuels from biomass to reduce this impact. Such production, however, requires land to produce the biomass with the associated risk of impacts on biodiversity. As a step towards examining this impact, an assessment methodology was developed that integrates statistical modeling, remote sensing, and field studies to characterize landuse changes with respect to ecosystem diversity. This does not address other aspects of biodiversity such as genetic or species diversity. This study investigates the applicability of vegetation fraction derived from spectral reflectance as an indicator of biodiversity. Indices based on regression models between each landuse types and reflectance values from Landsat Thematic Mapper. The Normalized Difference Vegetation Index (NDVI) is used for measurement of green biomass and ecosystem diversity. NDVI values for diversity assessment and monitoring are used to map vegetation land cover with a special emphasis on agriculture. The vegetation dynamics in the context of different land cover types lead to variations in the spectral radiance in ecosystem diversity indicator values. Preliminary results applied to an example from Southeastern Ontario indicated a positive correlation between NDVI values and vegetation diversity.

1. Introduction

As one of many initiatives in support of its commitment to the Kyoto protocol, the Canadian government has announced "The Ethanol Expansion Program". This program proposes the greater use of bioethanol as an alternate fuel for reducing greenhouse gas (GHG) emissions with the aim of having at least 35 percent of gasoline contain 10 percent bioethanol by 2010 (The Government of Canada, 2003). This is the driving force behind growing more energy crops such as corn for bioethanol production. Meeting such a production target may require changes in land-use with consequent threats to biodiversity. Agricultural land-use practices must be adapted to minimize this impact through, for example, higher crop yields, improved soil quality and enhanced agroecosystem diversity. Loss of agricultural biodiversity is believed to stem from one or more of six major causes: 1) Policies: promote/support homogenized monocultural high-chemical-input farming systems, such as energy crop for bioethanol, etc. 2) Agricultural/rural development programs: support conventional industrial patterns of uniform monocultural development and reduce biodiversity 3) Pressures: private sector interests that perpetuate the sales and use of uniform seeds and related chemical inputs 4) Inequities in the distribution of, and access to, resources, including genetic resources 5) Lack of participation of farmers and stewards of agrobiodiversity in decision-making and program development in agriculture 6) Neglect (or suppression) of local and indigenous knowledge about genetic resources and biodiversity in this arena (Boyle, 1991). Remote sensing has become a potential tool for conservation biology. Satellite images provide an overall picture of a landscape and a means to map and monitor habitat changes from field observations. Data from remote sensing are one of the most important sources of information for land cover classification (Avery and Berlin, 1992). Landsat-TM satellite imagery is used to determine present landuse within each natural vegetation zone, and to map distribution and relative abundance of landscape diversity (Chen and Brutsaert, 1998). The Normalized Difference Vegetation Index (NDVI) is an index that provides a standardized method of comparing vegetation greenness between satellite images (Paruelo and Epstein, 1997, Oesterheld and DiBella, 1998 and Ricotta and Avena, 1999). The Shannon-Wiener landuse diversity index (SHDI) is very useful in monitoring temporal changes or in describing spatial variation within a broad study area. If one wants to measure "biodiversity" there are no less than 12 different definitions to choose (Boyle, 2000). However, the Shannon index has been the most widely used in community ecology and ecosystem diversity. It does not, however, address genetic or species diversity.

The main objective of this study is to integrate statistical modeling, remote sensing, and field studies to characterize landuse changes and ecosystem diversity. Data from remote sensing is one of the most important sources of information for land cover classification (Avery and Berlin, 1992). Landsat-TM satellite imagery is used to determine present landuse within each natural vegetation zone, and to map distribution and relative abundance of landscape diversity (Chen and Brutsaert, 1998). The Normalized Difference Vegetation Index (NDVI) is an index that provides a standardized method of comparing vegetation greenness between satellite images (Oesterheld and DiBella, 1998 and Ricotta and Avena, 1999).

2. Materials and Methodology

2.1 Materials

2.1.1 Study area

The study area is located in the southeastern part of the province of Ontario. The boundary of this area is located at 44° 15′ – 45° 37′ 5″ N and 74° 10′ – 75° 55′ 2″ W and contains 4 eco-districts. It covers an area of about 5,900.29 square kilometers. It is bordered to the south by the north shore of the eastern end of Lake Ontario and the western end of the St. Lawrence River. Eastern Ontario as a whole is a largely rural region, filled with abundant natural resources and agricultural opportunities. Major geographic features of the region include Lake Ontario on the south and the many lakes and waterways (including both the Trent-Severn and Rideau River waterways) scattered throughout the region. It contains 4 Eco-districts that is in the Mixed Wood Plain Ecozone. Each Eco-district is characterized by relatively homogeneous biophysical and climatic conditions. The differentiating characteristics of the Eco-districts are: regional landform, local surface form, permafrost distribution, soil development, textural group, vegetation cover/landuse types, range of annual precipitation, and mean temperature.

2.1.2 Remotely sensed data

Landsat TM data of May 4, 2003 was used. The selected data was derived from: Path-row: 15-28 Date and Path-row: 15-29.

2.2 Methodology

The principle of methodology is based essentially to correlate ecosystem diversity determined by field observations to remotely captured data for landuse and vegetation cover. With this correlation established, forecasted changes to land-use can were related to the consequent impacts on biodiversity. The framework of the study is schematically shown in the Figure 1.

2.2.1 Preprocessing

Preprocessing comprising of geometric correction using orthorectification and mosaic of Landsat TM data for two scenes were performed before image classification.

2.2.2 Landuse classification

This study utilizes the ENVI software for landuse classification. Supervised classification for this study was based on the typical signatures obtained from the training of the classification system which came from field observation that was modified from Agriculture and Agri-Food Canada's definitions as shown in Table 1.

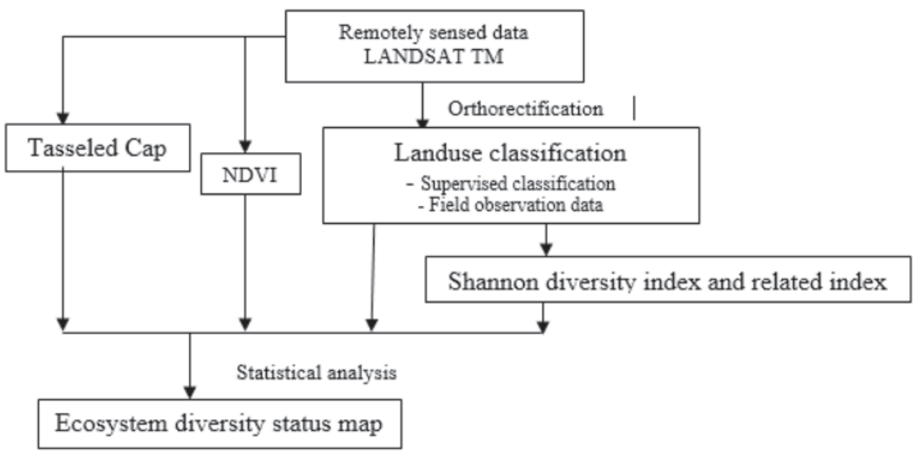

Figure 1: Methodology framework of the study

Table 1: Landuse types and definition

Land use types	Definition
Forest/trees	Hardwoods, mixed woods, recent burns, cut overs
Wetlands	Intermittent water bodies, areas that have semi-permanent or permanent wetland vegetation, including fens, bogs, swamps, sloughs, marshes etc.
Shrubland	Land that has perennial, woody shrub coverage
Pasture	Grasslands, rangelands and pasture: native vegetation with <10% tree cover
Other agriculture	all other or nonspecific agricultural lands
Mixed wood	Neither coniferous nor broadleaf tree account for 75% or more of total basal area.
Deciduous	Broadleaf trees that are 75% or more of total basal area including coniferous trees are 75% or more of total basal area.
Cropland	Annually cultivated land

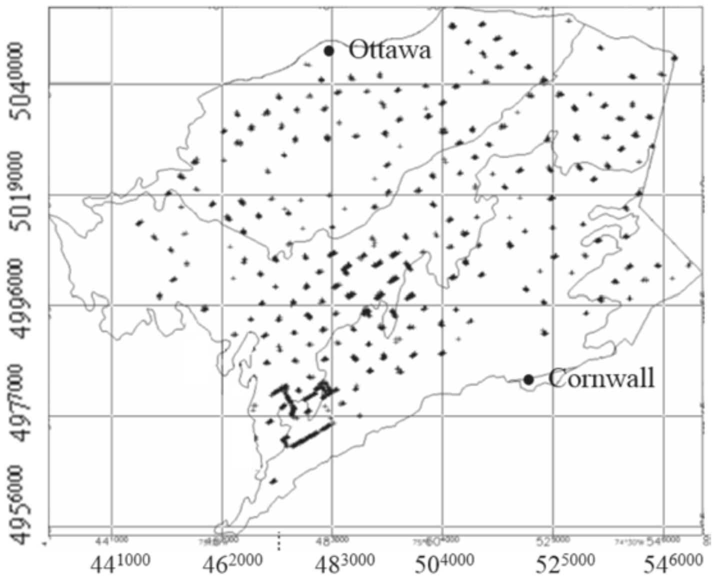

Figure 2: Sampling points in this study area

2.2.3 Sampling sites for supervised classification

There are 1,948 sampling points in this study area as shown in Figure 2 (courtesy of Agriculture and Agri-Food Canada). The field work for the study was undertaken in July, August and September in 2003. The field observation is an integral part of collecting the training information as well as conducting the accuracy assessment study.

2.2.4 Shannon diversity index (SHDI)

The Shannon Diversity Index (SHDI) (EEA and ETC, 1999) quantifies the diversity of the countryside based on two components: the number of different landuse types and the proportional area distribution among landuse types. The two components are commonly named richness and evenness. Richness refers to the number of landuse types (compositional component) and the evenness to the area distribution of classes (structural component). The Shannon Index is calculated by adding, for each landuse type present, the proportion of area covered, multiplied by that proportion expressed in natural logarithm, according to the formula:

$$SHDI = -\sum_{i=1}^{m} (P_i * \ln P_i)$$

Equation 1

Where, m = number of landuse types, P_i = proportion of area covered by landuse type (land cover class) i

SHDI addresses the number and relative abundance of landuse types, but does not include how these types are distributed (Rosenzweig, 1995).

2.2.5 The Normalized difference vegetation index (NDVI) data analysis

NDVI can be used as an indicator of relative biomass and greenness (Boone et al. 2000 and Chen and Brutsaert, 1998). If sufficient ground data is available, the NDVI can be used to calculate and predict primary production, dominant species, and grazing impact and stocking rates (Ricotta and Avena, 1999, Oesterheld and DiBella, 1998, Paruelo and Epstein, 1997, Peters et al. 1997). Nevertheless, NDVI has seen its most significant application in relation to species richness and abundance (Diallo et al. 1991) The NDVI transformation is computed as the ratio of the measured intensities in the red (R) and near infrared (NIR) spectral bands using the following formula:

$$NDVI = (NIR - red) / (NIR + red)$$

This study utilizes the ENVI software for NDVI Data analysis from Landsat Thematic Mapper (TM) imagery. Landsat TM, bands 3 and 4 provide R and NIR measurements and therefore can be used to generate NDVI dataset.

2.2.6 Tassled cap transformation

The Tassled Cap Transformation is one form of several linear data transformations developed to reduce the number of spectral channels required in vegetation and soils studies. Three Tassled Cap components were calculated for the TM image in this study. The soil brightness index (SBI) is a weighted sum of all 6 TM channels and, as such, is a response to changes in total reflectance, driven primarily by soil reflectance changes. The greenness index (GI) is the sum of the visible and near infrared bands, and has been shown to be moderately well-correlated to percentage canopy coverage, Leaf Area Index and fresh biomass. The wetness index (WI) is related to soil features, including moisture status (Jensen, 1986). Finally, wetness contrasts the sum of the visible and near infrared channels against the sum of the longer wavelength bands, and is named due to the sensitivity of the longer infrared channels to soil (Schmidt and Karnieli, 2000).

2.2.7 Statistical analysis

Shannon diversity index is estimated using Landsat TM data as following: Each parameter is calculated from a 10x10 sub-image through sampling 20 locations (5 locations from each eco-district) from the whole image. The multiple regression analysis was applied to determine correlations between TM data and Shannon Diversity Index data. The following parameters were analyzed considering the characteristics of remote sensing data: soil brightness index (SBI), greenness index (GI), wetness index (WI), normalized different Vegetation Index (NDVI)

2.2.8 Scenario Analysis

General Scenario Description: the total energy crop area is increased 5% every 5 years from 2003 to 2018, and the other landuse types are proportionally decreased. Three scenarios are analyzed as follows:

Scenario 1: convert non-native land to energy crop – the change from shrub land, pasture land, other agricultural and crop land types to energy crop is in the range of 8-29% for each type over 15 years.

Scenario 2: convert 5% of each landuse type (native and non-native) to energy crop every 5 years;

Scenario 3: convert native land (all forest land and parts of deciduous area) to energy crop over 15 years.

3. Results and Discussion

3.1 Supervised Classification

The final result is a classified land cover map representing forests, wetlands, shrubland, pasture, other agriculture area, mixwood, deciduous, cropland, built-up and water. Accuracy assessment studies are conducted after the imagery has been classified. These studies determine whether an image analyst has correctly identified the land cover as shown in Table 2. Table 2 is an error matrix that presents the user's and producer's accuracies of each class and the overall accuracy. The overall classification accuracy of habitat is 83.3%. The SHDI which was calculated from the equation 1 is equal to 1.903.

3.2 SHDI using Multivariate Regression Analysis

The first step was to produce a landscape diversity map employing the Shannon diversity index to the Landsat TM classified land cover map. Secondly, landscape diversity was observed on the basis of average biomass production measured from integrated NDVI data. The statistical model was found as follows:

$$SHDI = - 0.002*SBI - 0.051*GI - 0.001*WI - 0.0522*NDVI + 1.575 \quad (R=0.66)$$

Equation 2

Where:

SHDI is the Shannon diversity index from Equation 1
SBI is the soil brightness index from Landsat TM
GI is the greenness index from Landsat TM

WI is the wetness index from Landsat TM
NDVI is the normalized difference vegetation index from Landsat TM.

Although this is the best correlation that has been obtained so far, it can be further improved by higher resolution data and also much dense sampling. The vegetation biodiversity map generated from the statistical model (Equation 2) is shown in Figure 3. From figure 3, the map shows the levels of the Shannon diversity index (SHDI) that are divided into five categories:

1. The lowest SHDI area
2. The low SHDI area
3. The moderate SHDI area
4. The high SHDI area
5. The highest SHDI area.

The positive correlation between SHDI from terrestrial data and data from LANDSAT TM image data (GI, WI, NDVI) revealed R^2 values of 0.56, 0.28 and 0.08, respectively.

3.3 Shannon Diversity Index
The index calculated from Equation1 using the landuse area from satellite image classification is equal to 1.903. The average of SHDI from the statistical model (Equation 2) is equal to 1.39 ±0.25 (0.416-0.201).

3.4 Scenario Analysis
In order to address the issue – how to expand the land needed for energy crop production with minimum impact on ecosystem diversity – the following approach was developed. SHDI was calculated from the results of landuse classification in the study area in 2003 for three scenarios were found as shown in the Table 2. In the first scenario (S1), the percentage of total landuse change to energy crop production is equal to 5% and increasing 5% of total area every 5 years from 2003 to 2018. All this change is concentrated on non-native land (shrubland, pasture, cropland and other agricultural land). In the second scenario (S2), the percentage of total landuse change from all landuse types to energy crop is equal to 5%, and is increased by 5% every 5 years from 2003 to 2018. However, in S2, this change in landuse is distributed evenly among all landuse classes. In the third scenario (S3), landuse change is from all forest area and some parts of deciduous area to energy crop, and is increased by 5% of total area every 5 years from 2003 to 2018. The total land area was considered to be constant for all the three scenarios.

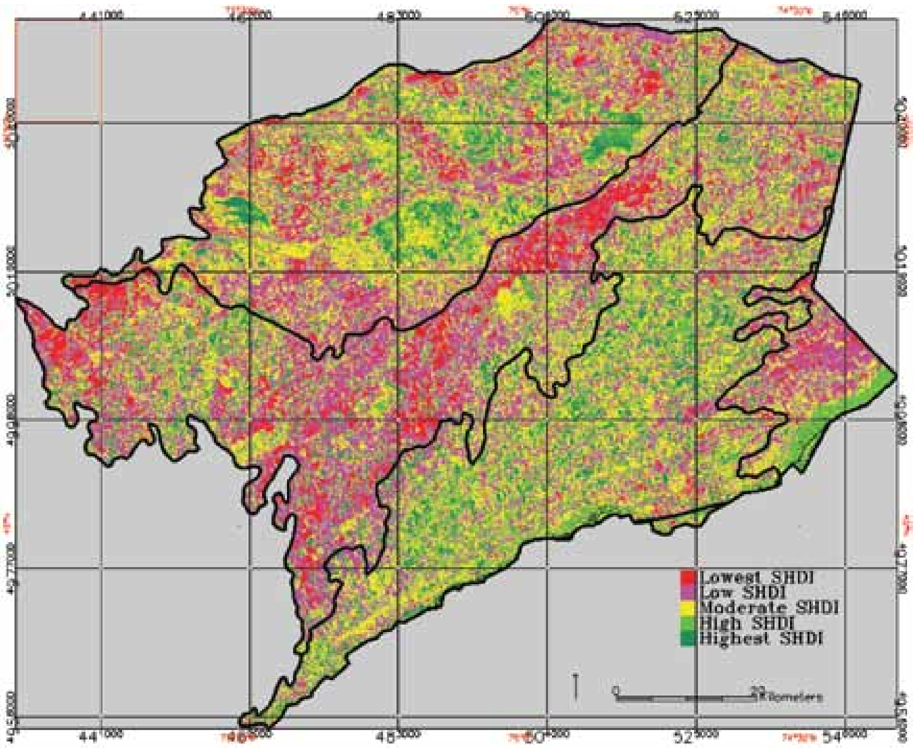

Figure 3: Ecosystem Diversity Map in Southeastern Ontario, Canada

Table 2: Resulting SHDI from the 3 scenarios

class	2003	2008					
	(km^2)	S1	%change	S2	%change	S3	%change
forest	218.3	218.3	0.0	207.4	-5.0	0.0	-100.0
wetland	627.2	627.2	0.0	595.9	-5.0	627.2	0.0
shrubland	511.4	462.6	-10.0	485.9	-5.0	511.4	0.0
pasture	627.1	573.8	-8.0	595.7	-5.0	627.1	0.0
otheragri	414.3	379.1	-9.0	393.6	-5.0	414.3	0.0
mixwood	521.1	521.1	0.0	495.1	-5.0	521.1	0.0
deciduous	1320.8	1320.8	0.0	1254.7	-5.0	1244.1	-5.8
cropland	1660.0	1502.3	-10.0	1577.0	-5.0	1660.0	0.0
energy crop		295.0	5.0	295.0	5.0	295.0	5.0
SHDI	1.903	2.010		2.007		1.924	
class	**2003**	**2013**					
	(km^2)	S1	%change	S2	%change	S3	%change
forest	218.3	218.3	-	196.5	- 10.0	-	-100.0
wetland	627.2	627.2	-	564.5	- 10.0	627.2	-
shrubland	511.4	413.9	- 19.0	460.3	- 10.0	511.4	-
pasture	627.1	520.5	- 17.0	564.4	- 10.0	627.1	-
otheragri	414.3	343.9	- 17.0	372.9	- 10.0	414.3	-
mixwood	521.1	521.1	-	469.0	- 10.0	521.1	-
deciduous	1320.8	1320.8	0.0	1188.7	- 10.0	949.1	-28.1
cropland	1660.0	1344.6	-19.0	1494.0	- 10.0	1660.0	0.0
energy crop		590.0	10.0	590.0	10.0	590.0	10.0
SHDI	1.903	2.043		2.038		1.970	
class	**2003**	**2018**					
	(km^2)	S1	%change	S2	%change	S3	%change
forest	218.3	218.3	0.0	185.6	-15.0	0.0	-100.0
wetland	627.2	627.2	0.0	533.2	-15.0	627.2	0.0
shrubland	511.4	365.1	-29.0	434.7	-15.0	511.4	0.0
pasture	627.1	467.2	-26.0	533.0	-15.0	627.1	0.0
otheragri	414.3	308.7	-26.0	352.2	-15.0	414.3	0.0
mixwood	521.1	521.1	0.0	442.9	-15.0	521.1	0.0
deciduous	1320.8	1320.8	0.0	1122.6	-15.0	654.1	-49.5
cropland	1660.0	1186.9	-29.0	1411.0	-15.0	1660.0	0.0
energy crop		885.0	15.0	885.0	15.0	885.0	10.0
SHDI	1.903	2.044		2.040		1.975	

From table 2, the SHDI from the third scenario is found to be the lowest, i.e., ecosystem diversity has been reduced the most. This is because the energy crop landuse change in the third scenario impacts on the forest ecosystem diversity, while the energy crop landuse change from the first scenario is limited to only non-native areas i.e., pasture land, existing crop land, etc. Thus, this approach can be used to estimate changes in the ecosystem or environment that occur over time in forest areas. The more energy crop planted in native areas, the greater will be the impact on overall ecosystem diversity. These scenarios all show the same projected trend over 15 years to 2018 of slight increases in the Shannon diversity index (SHDI) from 1.90 to 2.04. The higher the SHDI number, the greater is the vegetation diversity. The Shannon Diversity Index increases as the number of different landuse class increases and/or the proportional distribution of the area among patch types becomes more equitable. For a given number of classes, the maximum value of the Shannon Index is reached when all classes have the same area. The effect of this variation of evenness is reflected by the SHDI – the more equal the shares of the classes, the higher the Shannon Index (EEA and ETC, 1999). Vegetation diversity measures are not the total answer to diversity management because they do not directly address genetic or species diversity. However, they are one of the number of methods to describe, monitor, or compare specific sites. The methodology presented here has the advantage of being time-efficient and relatively low-cost. Application of the SHDI-remote sensing statistical model for ecosystem diversity to decision-making and policy development will be developed more extensively in future work.

4. Summary and Conclusion

Landsat-TM satellite imagery was used to determine present landuse within each natural vegetation ecosystem, and to map distribution and relative abundance landscape diversity. By measuring the rates of landuse changes from the satellite imagery, the impact of energy crop on the ecosystem diversity is predicted using the SHDI. Landsat TM data have been used to classify the study area into 8 land cover classes. The analysis revealed some interesting observations: the lowest Shannon Diversity Index was found in the cropland areas. The highest Shannon Diversity Index is in the forest area. The ecosystem diversity map indicated a general landuse distribution. From the analysis results, correlations between the Shannon Diversity Index and TM data were found to be the highest in the following items:

1. The soil brightness index / TM data.
2. The greenness index / TM data
3. The wetness index / TM data
4. The normalized difference vegetation index /TM data

The impact of energy crops on habitat and ecosystem diversity depends not only on the previous landuse and cultivation, but also on the nature of the energy crop. However, if the plantation displaced permanent woodlands, forest area or other environmentally sensitive habitats, then the impacts are likely to be negative. Energy crops can be grown on most of the 400 million acres classified as cropland in Canada. They offer many environmental advantages when produced on erosive lands or lands that are otherwise limited for conventional crop production. Guidelines for plantation developers can help to ensure that they are located in the appropriate areas and that they are designed to maximize, as far as possible, habitat diversity. While the potential positive impact of agricultural landuse change on regional ecosystem diversity is limited in the short term, it may be strengthened in the longer term.

Tracking the changes in biological diversity at the species level essentially entails understanding the distribution and abundance of species. For many species this is likely to need detailed monitoring over decades. Moving from present patterns of consumption and production to those that are truly sustainable is a major task. Future technological development will be important, as will the application of many existing technologies. Sustainable development is dependent upon balancing the interplay of policies and their effective implementation to achieve economic, environmental and social objectives. Researchers are presently developing knowledge-gathering, integration, and dissemination tools, and fostering partnerships necessary for the application of an ecosystem approach to resource management. How best to organize ongoing and future initiatives can be learnt through trial and error and the sharing of best practices. The goal of sustainable development demands an ecosystem-based approach for the exploitation of natural resources as well as application of optimal nature-preserving technologies. In turn, this necessitates a thorough understanding of the mechanisms underlying the function of natural ecosystems together with development of global and national strategies for environmental conservation and nature management. Dynamic systems models can make a valuable contribution to this cause.

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