Using Remote Sensing to Estimate the Impact of Landuse Practices on Ecosystem Diversity: An Example in Southeastern Ontario

S. Adsavakulchai¹*, D. Minns² and A. Chan²

¹School of Engineering, University of the Thai Chamber of Commerce, 126/1 Vibhavadi Rangsit Rd, Bangkok 10400 Thailand
e-mail : Suwannee_ads@utcc.ac.th
²National Research Council of Canada, 1200 Montreal Road, Ottawa, ON K1A 0R6 Canada

Abstract. The Shannon Diversity Index (SHDI) is one of the most widely-used measures of diversity in the ecology literature. Landsat thematic mapper (TM) has been used to map the SHDI from landuse classification, and the relationships between SHDI estimates and satellite-measured reflectance have been analyzed. The Normalized Difference Vegetation Index (NDVI) is used as an index for a rough measurement of green biomass and ecosystem diversity using a relatively simple and direct remote-sensing approach. 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 in southeastern Ontario, where four eco-districts were considered, indicate a positive correlation between Landsat TM reflectance and parameters related to SHDI. Three hypothetical landuse change scenarios were applied to the sample region to estimate the potential impact of energy cropping on biodiversity.

Keywords: landuse, ecosystem diversity, southeastern Ontario, remote sensing, NDVI

Introduction

The Ethanol Expansion Program, jointly supported by the Canadian Renewable Fuels Association and the Government of Canada (http://www.greenfuels.org/envirobenefits.html), not only will be a significant step forward for the Canadian renewable fuels industry, but is also an important initiative for meeting Canada’s commitment toward a better environment. This program is expected to increase Canada’s ethanol production capacity to support current and proposed programs for blending ethanol in gasoline. It is an important step towards reaching the Climate Change Plan proposed target of having at least 35 percent of the gasoline used in Canada contain 10 percent ethanol by 2010 (The Government of Canada, 2003). Whereas current annual production is about 200 million liters (http://www.nrcan-rncan.gc.ca/media/newsreleases/2004/200402_e.htm), and 7 percent of gasoline sold in Canada is currently blended with ethanol, the new target for 2010 would require 1.4 billion liters of ethanol a year (http://biz.yahoo.com/rm/040216/energy_canada_ ethanol_1.html). This is the driving force behind growing energy crops for bioethanol integrated into the concept of sustainable agriculture and seeking benefits through higher crop yields, improved soil quality and agroecosystem diversity.

Current use of corn for producing the feedstock for bioethanol may be a good place to start developing the industry but uses agricultural practices that are not sustainable. In the longer term changing to native plants or woody shrubs may provide a more sustainable approach and provide benefits in water conservation and preservation of soil quality.
Changes in landuse and agricultural practices are believed to relate to six major causes of loss of agricultural ecosystem diversity:

a) policies that promote/support homogenized monocultural high-chemical-input farming systems, such as energy crop for bioethanol, etc.;
b) agricultural/rural development programs that support conventional industrial patterns of uniform monocultural development and reduce biodiversity;
c) pressures by private sector interests that perpetuate the sales and use of uniform seeds and related chemical inputs;
d) inequities in the distribution of, and access to, resources, including genetic resources;
e) lack of participation of farmers and stewards of agrobiodiversity in decision-making and program development in agriculture;
f) neglect (or suppression) of local and indigenous knowledge about genetic resources and biodiversity in this arena (Boyle, T.J.B., 1991).

Remote sensing is 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.

The main objective of this study is to integrate statistical modeling, remote sensing, and field studies to characterize landuse change and ecosystem diversity. Data from remote sensing is one of the most important sources of information for land cover classification (Avery, T.E. et al., 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, D. et al., 1998). The Normalized Difference Vegetation Index (NDVI) is an index that provides a standardized method of comparing vegetation greenness between satellite images (Paruelo et al., 1997; Oesterheld et al., 1998 and Ricotta et al., 1999).

**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, as shown in Fig. 1. It covers an area of about 5900.29 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 classes, range of annual precipitation, and mean temperature.

The city of Cornwall is a strategic location in prosperous eastern Ontario. Agricultural lands occupy 51% of the lands in Stormont County. Row crops, such as corn, are the mainstay of local agriculture and continue to grow in size and importance in the area. Corn occupies 58% of farmed land, pasture 17%, summer fallow 1%, and other uses 2%. Particularly, the city of
Cornwall has excess capacity in its water purification and treatment systems at competitive rates. Cornwall Electric offers attractively priced hydroelectric power to industries. Central Gas Ontario will be the supplier of natural gas to the site.

Seaway Grain Processors, Inc. of Cornwall, Ontario is one of seven ethanol projects from across Canada that will receive government funding. The Government of Canada selected the companies' proposals for construction of new fuel ethanol facilities as part of a competitive process under the Ethanol Expansion Program. The first round of the program totals $78 million in contributions, and the share to the Cornwall project is $10.5 million for a facility that will produce 66 million liters of fuel ethanol annually (Cornwall Economic Development & Recreation Services).

![Image of Study Area in Southeastern Ontario, Canada]

**Sampling Sites for Supervised Classification**

There are 1,948 sampling points in this study area as shown in Fig. 2 (courtesy of Agriculture and Agri-Food Canada). The field work for the study was undertaken in July, August and September in 2003.

**Satellite Data** (courtesy of Agriculture and Agri-Food Canada).

Landuse was further examined in the present study by using Landsat TM data. The selected data was derived from:

Methodology

The approach for the study is schematically shown in Fig. 3.

Preprocessing

The study area was covered by two scenes of TM data. Geometric correction using orthorectification and mosaic was performed.
Data Input

1,948 sampling points in this study area (courtesy from Agriculture and Agri-Food Canada) are applied for supervised classification.

Landuse Classification

This study utilizes the ENVI software for land use classification following Agriculture and Agri-Food Canada definition as shown in Table 1.

Table 1: Landuse types and definition

<table>
<thead>
<tr>
<th>Land use types</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest/trees</td>
<td>hardwoods, mixed woods, recent burns, cut overs</td>
</tr>
<tr>
<td>Wetlands</td>
<td>intermittent water bodies, areas that have semi-permanent or permanent wetland</td>
</tr>
<tr>
<td>Shrubland</td>
<td>vegetation, including fens, bogs, swamps, sloughs, marshes etc.</td>
</tr>
<tr>
<td>Pasture</td>
<td>land that has perennial, woody shrub coverage</td>
</tr>
<tr>
<td>Other agriculture</td>
<td>grasslands, rangelands and pasture: native vegetation with &lt;10% tree cover</td>
</tr>
<tr>
<td>Mixed wood</td>
<td>all other or non specific agricultural lands</td>
</tr>
<tr>
<td>Deciduous</td>
<td>neither coniferous nor broadleaf tree account for 75% or more of total basal area.</td>
</tr>
<tr>
<td>Cropland</td>
<td>annually cultivated land</td>
</tr>
</tbody>
</table>

Source: modified from Agriculture and Agri-Food Canada

Shannon Diversity Index

The Shannon Diversity Index (SHDI) quantifies the diversity of the countryside based on two components: the number of different landuse types and the proportional area distribution among landuse types (EEA & ETC, 1999). The two components are commonly named richness and evenness. Richness refers to the number of landuse types (compositional component) and 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:

$$SHDI = - \sum_{i=1}^{m} (P_i \times \ln P_i)$$  
(Eq.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, M. L., 1995).
The Normalized Difference Vegetation Index (NDVI) Data Analysis

NDVI can be used as an indicator of relative biomass and greenness (Boone et al. 2000, Chen 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 et al. 1999, Oesterheld et al. 1998, Paruelo et al. 1997, Peters et al. 1997, Diallo et al. 1991). Nevertheless, NDVI has seen its most significant application in relation to species richness and abundance (Doherty, M., et al., 2000.) 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:

$$NDVI = \frac{(NIR - red)}{(NIR + red)}$$

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 data sets with the following formula:

$$NDVI = \frac{(Band 4 - Band 3)}{(Band 4 + Band 3)}$$

**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, J. R., 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, H. and A. Karnieli, 2000).

**Statistical Analysis** for Shannon diversity index: Estimation using Landsat TM data

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 terms were analyzed by considering the characteristics of remote sensing data:

- soil brightness index (SBI)
- greenness index (GI)
- wetness index (WI)
- normalized different Vegetation Index (NDVI)
- landuse classification (CLASS)
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.

Results and Discussion

Shannon Diversity Index: The index calculated from Equation1 by 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).

Supervised Classification: The accuracies of these eight landscapes is equal to 83.3%. The relationship between NDVI and landuse type from supervised classification is shown in Fig. 4. There are some overlapped among each landuse type. However, the result of landuse classification is based on training area, not NDVI.

![Figure 4: NDVI and landuse type from supervised classification](image)

Where
1. forest : hardwoods, mixed woods, recent burns, cut overs
2. wetland : intermittent water bodies, areas that have semi-permanent or permanent wetland
vegetation, including fens, bogs, swamps, sloughs, marshes etc.

3. shrubland : land that has perennial, woody shrub coverage
4. pasture : grasslands, rangelands and pasture: native vegetation with <10% tree cover
5. otheragri : all other or non specific agricultural lands
6. mixwood : neither coniferous nor broadleaf tree account for 75% or more of total basal area.
7. deciduous : broadleaf trees that are 75% or more of total basal area including coniferous trees are 75% or more of total basal area.
8. cropland : annually cultivated land

**Multiple Regression Analysis:** The first step was to produce a landscape diversity map by applying the Shannon diversity index to the Landsat TM classified land cover map. Secondly, landscape diversity has been observed on the basis of average biomass production measured from integrated NDVI data. The statistical model is as follows:

\[
\text{SHDI} = -0.002\times \text{SBI} - 0.048\times \text{GI} - 0.001\times \text{WI} - 0.0521\times \text{NDVI} - 0.048\times \text{CLASS} + 1.565
\]

\[\text{(Eq. 2)}\]

\[\text{(R}=0.65\)\]

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
- **CLASS** is the landuse classification from Landsat TM

Although this is the best correlation that has been obtained so far, it can be further strengthened, and more work needs to be done to find a statistical model with a higher correlation.

The vegetation biodiversity map generated from the statistical model (Eq. 2) is shown in Fig. 4. 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.
Figure 4: Ecosystem Diversity Map in Southeastern Ontario, Canada

Illustrative Application to Decision-Making

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 as shown in 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 held constant for all three scenarios.

Data summarized in Table 2 shows that the SHDI from the third scenario is 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.
Table 2: The 3 scenarios and the resulting SHDI

<table>
<thead>
<tr>
<th>class</th>
<th>2003 (km²)</th>
<th>S1</th>
<th>%change</th>
<th>S2</th>
<th>%change</th>
<th>S3</th>
<th>%change</th>
</tr>
</thead>
<tbody>
<tr>
<td>forest</td>
<td>218.3</td>
<td>218.3</td>
<td>0.0</td>
<td>207.4</td>
<td>-5.0</td>
<td>0.0</td>
<td>-100.0</td>
</tr>
<tr>
<td>wetland</td>
<td>627.2</td>
<td>627.2</td>
<td>0.0</td>
<td>595.9</td>
<td>-5.0</td>
<td>627.2</td>
<td>0.0</td>
</tr>
<tr>
<td>shrubland</td>
<td>511.4</td>
<td>462.6</td>
<td>-10.0</td>
<td>485.9</td>
<td>-5.0</td>
<td>511.4</td>
<td>0.0</td>
</tr>
<tr>
<td>pasture</td>
<td>627.1</td>
<td>573.8</td>
<td>-8.0</td>
<td>595.7</td>
<td>-5.0</td>
<td>627.1</td>
<td>0.0</td>
</tr>
<tr>
<td>otheragri</td>
<td>414.3</td>
<td>379.1</td>
<td>-9.0</td>
<td>393.6</td>
<td>-5.0</td>
<td>414.3</td>
<td>0.0</td>
</tr>
<tr>
<td>mixwood</td>
<td>521.1</td>
<td>521.1</td>
<td>0.0</td>
<td>495.1</td>
<td>-5.0</td>
<td>521.1</td>
<td>0.0</td>
</tr>
<tr>
<td>deciduous</td>
<td>1320.8</td>
<td>1320.8</td>
<td>0.0</td>
<td>1254.7</td>
<td>-5.0</td>
<td>1244.1</td>
<td>-5.8</td>
</tr>
<tr>
<td>cropland</td>
<td>1660.0</td>
<td>1502.3</td>
<td>-10.0</td>
<td>1577.0</td>
<td>-5.0</td>
<td>1660.0</td>
<td>0.0</td>
</tr>
<tr>
<td>energy crop</td>
<td>295.0</td>
<td>295.0</td>
<td>5.0</td>
<td>295.0</td>
<td>5.0</td>
<td>295.0</td>
<td>5.0</td>
</tr>
<tr>
<td>SHDI</td>
<td>1.903</td>
<td>2.010</td>
<td>2.007</td>
<td>1.924</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>class</th>
<th>2003 (km²)</th>
<th>S1</th>
<th>%change</th>
<th>S2</th>
<th>%change</th>
<th>S3</th>
<th>%change</th>
</tr>
</thead>
<tbody>
<tr>
<td>forest</td>
<td>218.3</td>
<td>218.3</td>
<td>0.0</td>
<td>196.5</td>
<td>-10.0</td>
<td>-100.0</td>
<td>-100.0</td>
</tr>
<tr>
<td>wetland</td>
<td>627.2</td>
<td>627.2</td>
<td>0.0</td>
<td>564.5</td>
<td>-10.0</td>
<td>627.2</td>
<td>0.0</td>
</tr>
<tr>
<td>shrubland</td>
<td>511.4</td>
<td>413.9</td>
<td>-19.0</td>
<td>460.3</td>
<td>-10.0</td>
<td>511.4</td>
<td>0.0</td>
</tr>
<tr>
<td>pasture</td>
<td>627.1</td>
<td>520.5</td>
<td>-17.0</td>
<td>564.4</td>
<td>-10.0</td>
<td>627.1</td>
<td>0.0</td>
</tr>
<tr>
<td>otheragri</td>
<td>414.3</td>
<td>343.9</td>
<td>-17.0</td>
<td>372.9</td>
<td>-10.0</td>
<td>414.3</td>
<td>0.0</td>
</tr>
<tr>
<td>mixwood</td>
<td>521.1</td>
<td>521.1</td>
<td>0.0</td>
<td>469.0</td>
<td>-10.0</td>
<td>521.1</td>
<td>0.0</td>
</tr>
<tr>
<td>deciduous</td>
<td>1320.8</td>
<td>1320.8</td>
<td>0.0</td>
<td>1188.7</td>
<td>-10.0</td>
<td>949.1</td>
<td>-28.1</td>
</tr>
<tr>
<td>cropland</td>
<td>1660.0</td>
<td>1344.6</td>
<td>-19.0</td>
<td>1494.0</td>
<td>-10.0</td>
<td>1660.0</td>
<td>0.0</td>
</tr>
<tr>
<td>energy crop</td>
<td>590.0</td>
<td>590.0</td>
<td>10.0</td>
<td>590.0</td>
<td>10.0</td>
<td>590.0</td>
<td>10.0</td>
</tr>
<tr>
<td>SHDI</td>
<td>1.903</td>
<td>2.043</td>
<td>2.038</td>
<td>1.970</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>class</th>
<th>2003 (km²)</th>
<th>S1</th>
<th>%change</th>
<th>S2</th>
<th>%change</th>
<th>S3</th>
<th>%change</th>
</tr>
</thead>
<tbody>
<tr>
<td>forest</td>
<td>218.3</td>
<td>218.3</td>
<td>0.0</td>
<td>185.6</td>
<td>-15.0</td>
<td>0.0</td>
<td>-100.0</td>
</tr>
<tr>
<td>wetland</td>
<td>627.2</td>
<td>627.2</td>
<td>0.0</td>
<td>533.2</td>
<td>-15.0</td>
<td>627.2</td>
<td>0.0</td>
</tr>
<tr>
<td>shrubland</td>
<td>511.4</td>
<td>365.1</td>
<td>-29.0</td>
<td>434.7</td>
<td>-15.0</td>
<td>511.4</td>
<td>0.0</td>
</tr>
<tr>
<td>pasture</td>
<td>627.1</td>
<td>467.2</td>
<td>-26.0</td>
<td>533.0</td>
<td>-15.0</td>
<td>627.1</td>
<td>0.0</td>
</tr>
<tr>
<td>otheragri</td>
<td>414.3</td>
<td>308.7</td>
<td>-26.0</td>
<td>352.2</td>
<td>-15.0</td>
<td>414.3</td>
<td>0.0</td>
</tr>
<tr>
<td>mixwood</td>
<td>521.1</td>
<td>521.1</td>
<td>0.0</td>
<td>442.9</td>
<td>-15.0</td>
<td>521.1</td>
<td>0.0</td>
</tr>
<tr>
<td>deciduous</td>
<td>1320.8</td>
<td>1320.8</td>
<td>0.0</td>
<td>1122.6</td>
<td>-15.0</td>
<td>654.1</td>
<td>-49.5</td>
</tr>
<tr>
<td>cropland</td>
<td>1660.0</td>
<td>1186.9</td>
<td>-29.0</td>
<td>1411.0</td>
<td>-15.0</td>
<td>1660.0</td>
<td>0.0</td>
</tr>
<tr>
<td>energy crop</td>
<td>885.0</td>
<td>885.0</td>
<td>15.0</td>
<td>885.0</td>
<td>15.0</td>
<td>885.0</td>
<td>10.0</td>
</tr>
<tr>
<td>SHDI</td>
<td>1.903</td>
<td>2.044</td>
<td>2.040</td>
<td>1.975</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

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 classes 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 & ETC, 1999).

Vegetation diversity measures are not a total answer to diversity management because they do not directly address genetic or species diversity. However, they are one of a 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.

Conclusion

Landsat-TM satellite imagery was used to determine present landuse within each natural vegetation zone, and to map distribution and relative abundance landscape diversity. By measuring the rates of landuse classification from 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 is in the cropland area. The highest Shannon diversity index is in the forest area. The general map indicates 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 more than 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 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.

Moreover, monitoring changes in biological diversity at the species level essentially entails 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 needs. Economic growth requires a secure and reliable energy supply, but is sustainable only if it does not threaten the environment and social welfare. Energy cropping to produce bioethanol, for example, could, if done properly, play a role in achieving a cleaner environment for Canada in a sustainable
development context. Its potential impact on biodiversity needs to be properly analyzed and understood so that its implementation will yield the maximum environmental benefits.

Acknowledgements: Dr. Ian Jarvis (Agriculture and Agri-Food Canada) has generously supplied the LANDSAT TM data and agricultural information for Southeastern Ontario. Special thanks are due to Thierry Fisette for helping in processing the LANDSAT TM data. This work is based on the author’s postdoctoral research at the National Research Council Canada, co-sponsored by the Thailand Research Fund.

References

9. Melvyn F. Askew The Central Science Laboratory, United Kingdom, IFA AGRICULTURAL CONFERENCE ON MANAGING PLANT NUTRITION 29 June - 2 July 1999, Barcelona, Spain BIOFUELS.
10. NASA Earth Observatory: Measuring Vegetation (NDVI and EVI) http://earthobservatory.nasa.gov/Library/MeasuringVegetation/