Using Dynamic Systems Modeling For Landuse Change Impact on Biodiversity in Canada

Adsavakulchai, S.\textsuperscript{1}, Minns, D.\textsuperscript{2}

\textsuperscript{1}126/1 Vibphavadee Rangsit Rd., School of Engineering, Thailand 10400
e-mail : suwannee_ads@utcc.ac.th
\textsuperscript{2}National Research Council Canada

Abstract

The differences among the land use change which will be described the structure of the changes in the uses of land from one type to another – and explains why these changes occur, what causes these changes, what are the mechanisms of change. Changes in the land use and the biodiversity are thought to be five major causes of loss of agricultural biodiversity a) policies that promote/support homogenized monocultural high-chemical-input farming systems (such as subsidies, credit policies, 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; and f) neglect (or suppression) of local and indigenous knowledge about genetic resources and biodiversity, along with reductionist and uni-disciplinary scientific paradigm.

Keywords: biodiversity, dynamic systems modeling, landuse change, Canada

1. Introduction

Currently, bioethanol production uses biomass i.e. plant matter to produce the transportation fuels. Actually, to use of biomass as a fuel offers some environmental advantages over fossil fuels like coal and oil, but can also have significant negative impacts on the environment. Some environmental groups support development of biomass energy depending on factors such as: choice of biomass used to make the fuel (e.g. crop wastes, canola, soybean, animal fat, etc.), the manner in which crops are farmed (whether there is heavy use of pesticides and fertilizers, use of irrigation, etc.) and the effectiveness of pollution controls used when energy is generated. Bioethanol made from sugar or starch-holding crops can be added to gasoline. Intensive agriculture is one of the most important causes for decline of plants and animal species. The pressure exerted through the disturbance of soil, with its accompanying nitrates loss and water extraction, the disturbance of breeding places and natural plant societies, and the use of pesticides, all contribute to the loss of biodiversity \[1\]. The agriculture, forestry and energy sectors are particularly vulnerable to criticism and possible sanctions for their perceived impact on the environment. Concern often is focused on declining biodiversity caused by habitat conversion and degradation. Robust technology for detecting and measuring changes in biodiversity is an important instrument in the environmental assessment process.

The main objective of this study is to develop and test a dynamic systems modeling, called landuse change impact on biodiversity (LCIB). It will provide the capability to conduct and participate in assessments of the impact of energy crop on biodiversity. The study will lead in development of the technology and expertise needed to conduct comprehensive biodiversity assessments in Canadian in support of environmental sustainability.
2. Modeling Approach, Scope and Assumptions of the Model

To design and develop a demonstration model of the impacts of energy on biodiversity, this study resulted in a foundation only for the design and development of dynamic models. This model should not yet be incorporated into actual land management policy decisions.

The STELLA software also provides a variety of tools that facilitate documentation and presentation of the model as a structured "learning environment" [2]. To integrate the concept of energy crop impact on biodiversity and sustainable development using STELLA software is shown in Fig. 1.

![Figure 1: Schematic diagram of procedure steps using STELLA in this study](image)

From Fig. 1 The methodology starts from identifies a problem, develops a dynamic hypothesis explaining the cause of the problem, builds a computer simulation model of the system at the root of the problem, tests the model to be certain that it reproduces the behavior seen in the real world, devises and tests in the model alternative policies that alleviate the problem, and implements this solution. Rarely is one able to proceed through these steps without reviewing and refining an earlier step.

3. Model Development

A model developed to analyze the impacts of energy crop on biodiversity was evaluated using model validation methods. The construction of a landuse change impact on biodiversity (LCIB) model with STELLA is an interactive process. LCIB consists of five modules: landuse and ecosystem transition, ecosystem production, bioethanol conversion, biodiversity and landuse as shown in Fig. 2.
Figure 2: STELLA diagram of landuse dynamics
4. Scenario Analysis

The scenarios considered all assume that the total area in this study remains constant. Landuse change between classes is modeled, i.e. pasture to energy crop land, energy crop to pasture; other agricultural land to energy crop land, energy crop land to other agricultural land, summer-fallow and cropland to energy crop land, and so on.

Scenario 1: This base case scenario models the continued use of energy crop for producing bioethanol. Through trial and error, the model derives a set of coefficients to track the historical time series and projects the transient impact on species diversity as shown in Figure 3.

Scenario 2: The base case was run with the 2010 target for bioethanol production, imposed on summer-fallow land, as shown in Figure 4. Comparisons of the impact with and without the driving force on species diversity are shown in Figures 5.1 and 5.2. From Figure 5.1, it can be seen that the impact of bioethanol on biodiversity in the short term is not significant. However, the impact of bioethanol on biodiversity in the longer term (e.g., 50 years) is more discernable, as shown in Figure 5.2.

For sensitivity analysis, the conversion of summer-fallow land to energy crop land is changed by ± 30%, as shown in Figure 6. In these cases, in order to meet the 2010 target for bioethanol production, the conversion of other land classes (i.e., pasture land, crop land) to energy crop land will be automatically balanced by the model. It can be seen that the more summer-fallow land allocated to energy crops, the lower will be the species diversity.

As an additional test of sensitivity, the imposed conversions of other agriculture crop land and pasture land to energy crop land are compared to the conversion of summer-fallow land already shown in Figure 12. The result, as shown in Figure 7, suggests that the impact on species diversity from the conversion of other agriculture crop land or pasture land to energy crop land can be expected to be less than that of summer-fallow land. This is perhaps related to the recovery of nutrients and microorganisms in the soil in the case of summer-fallow, thus impacting positively on biodiversity.

5. Results and Discussion

One significant potential area of negative impact of energy crop is related to the use of agrochemicals, soil erosion, visual intrusion, and changes to the ecosystem. However, these impacts are usually local in nature, reversible and can be minimized or avoided by adoption of best practice and other amelioration techniques. It is difficult to generalize the environmental impacts of bioethanol derived from energy crops, as they are site and crop dependent. There is also limited experience on the cultivation and generation phases of the energy crop fuel cycle.

The dynamic systems model does not predict a constant level of biodiversity for a certain combination of parameters, but rather, a pattern of fluctuations within limits established by the dynamic equilibrium of the model. In this case, man-made disturbances act upon ecosystems to modify the distribution of habitats over time and space. Species differ from one another in the ways in which they use and transform resources, in their impact upon their physical and chemical environment and in their interaction with others species. Interactions among species may generate positive and negative feedback at the ecosystem level. Given the complexity and variability of the interactions involved, the effects are usually difficult to establish. Particularly in food chains, changes in one functional group may have important consequences on the dynamics and production of other functional groups. Greater biodiversity is more favorable toward the production and stability of ecosystems. The productivity of ecosystem
Figure 3: Base case without driving force

Figure 4: Base case with driving force to change from SF to EC

Figure 5.1: Comparison between base case with and without driving force (Short term)
Figure 5.2: Comparison between base case with and without driving force (Long term)

Figure 6: Base case + Bioethanol required land from summer-fallow by ± 30%

Figure 7: Species diversity impact from driving force to change from 1.SF to EC 2.OC to EC 3.P to EC
depends closely upon the availability of the nutrient controlling the primary productions upon which trophic chain are founded. The flow of nutrients is controlled by chemical processes and the biological components in the ecosystem. Nitrogen is the most important constituent in plants after carbon. However, the quantities of nitrogen forms that can be found in the soil are insufficient to ensure the growth of plants. The major interactions among plant roots, animal, and microbes that take place under the soil surface directly determine what grows in which place and how [11].

One focus of the LCIB model is to demonstrate the demand pull approach and the corresponding impact on future biodiversity. Based on some rough estimates and recognizing the inherent difficulties with imprecise data and the use of projections, the model is used to explore possible landuse changes to achieve a 2010 target for energy crop on a regional and national basis. Access to meaningful data on a regional basis could be enhanced by a standardized national system of recording census returns. A list of topics not addressed by the present model follows:

- The economic and social impact of limits being set on the total amount of water that can be allocated
- Allocation policies and inter-regional attitudes toward irrigation of agricultural land
- The conflict between agricultural, industrial, amenity and environmental demands
- The need for more scientific evidence to support restrictive allocation policies
- Dealing with over-allocated resources
- Promoting efficient use – allocating water permits according to soil type or crop usage (crop evapotranspiration rates to become a consideration in the allocation process)
- Environmental impacts in terms of water quality (nitrate levels), habitat loss from diversion, flood risk due to damming and diverting watercourses.

The environmental impact of energy crop for ethanol in terms of soil loss from agricultural chemicals could be considerable [12]. The ecological function scenarios, soil properties, and potential crops and residue were prepared as common boundary conditions and driving variables for the model. The rate of soil erosion from managed lands depends on soil characteristics and the crop. Another practice gaining some attention is organic farming, which employs agronomic practices minimizing or eliminating highly processed chemical inputs, stressing soil building programs, and long term environmental sustainability. Methods include the use of crop rotations, natural insect predators, and organic nutrient sources, as opposed to the use of pesticides, fungicides, insecticides, and chemical fertilizers.

Crop rotation is a common practice on sloping soils because of its potential for soil saving [13]. Crops are changed year by year in a planned sequence. Sustainable agriculture is based upon healthy soil. Rotating crops increases the biodiversity of the farm both within and on top of the soil. Crop rotation breaks many weed and other pest life cycles, improves nutrient availability and utilization, and helps build healthy soil, especially where sod crops are grown [14].

The LCIB model was used to simulate a series of scenarios to gain some insight on the potential impact of energy cropping on species diversity. Under an aggressive campaign to use energy crop to increase the production of bioethanol, to meet the
prospective 2010 target, for example, there is likely to be an impact on species diversity. While there is enough summer-fallow land to fill the gap, a massive allocation of summer-fallow land to energy crop could impact negatively on biodiversity in the long term. The supplemental use of pasture land and other crop land on the margin, perhaps under a crop rotation regime, could help to ameliorate this negative impact.

6. Conclusion and Recommendation

Development of the Landuse Change Impact on Biodiversity (LCIB) model requires a multidisciplinary approach involving biology, ecology, chemistry, agronomy, geography, and regional planning. This study uses a system dynamics approach to develop a model for assessing the impact on biodiversity of agricultural landuse change driven by the demand of bioethanol at a regional scale. The model, linking the bioethanol requirement, landuse change and ecosystem functioning to biodiversity, can serve as an experimental platform for future policy analysis. It is a framework that integrates ecological function and biodiversity to strengthen the essential connections between the economic and environmental well-being. The model was validated structurally and behaviorally using the tests suggested by the literature, and then calibrated using Canadian agricultural landuse and crop production data over the last 10 years. The objective is to compare time-dependent ecological responses of landuse dynamics and species diversity modelled to track historical and projected transient forces across Canada. Historical data indicate that landused for energy crop production increased 27% over the last decade, while summer-fallow land declined to a low level. As a result, species diversity declined. Validation and calibration show that the model is capable of capturing the essential dynamics of landuse change and ecosystem functioning. Simulation results indicate that land allocated to energy crop production will likely increase in the next decade in order to meet the requirement from the bioethanol industry. Species diversity will likely decline as a consequence of agricultural landuse changes. An ecosystem approach facilitates the analysis of the trade-offs between efficiency and sustainability.

The impact of energy crops on habitat and biodiversity depends not only on the previous landuse and cultivation but also on the nature of the energy crop. However, if the plantation displaces 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 impact of agricultural landuse change on regional biodiversity may be limited in the short term, it could become more pronounced 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.

7. Acknowledgement

This work is based on the author’s postdoctoral research, jointly funded by the National Research Council of Canada and the Thailand Research Fund.

8. References

4. Bioethanol’s share of the transportation fuel market National Biofuels Program’s web site at www.ott.doe.gov/biofuels
5. Melvyn F. Askew The Central Science Laboratory, United Kingdom, IFA agricultural conference on managing plant nutrition 29 June - 2 July 1999, Barcelona, Spain BIOFUELS