LCIB : Assessing The Impact Of Energy Crop On Biodiversity Using Systems Dynamic Modeling

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Abstract - **This study uses a system dynamics approach to develop a model for assessing the impact on biodiversity of agricultural land use change driven by bioethanol industry at a regional scale. The Land use Change Impact on Biodiversity model (LCIB) is implemented in the STELLA. The model, linking the bioethanol requirement, land use change and ecosystem functioning to biodiversity, can serve as an experimental platform for future policy analysis. The model was validated structurally and behaviorally using the tests suggested by the literature, and then calibrated using last 10 years period Canadian agricultural land use and crop production data. It is to compare time-dependent ecological responses of land use dynamics and species diversity modeled to historical and projected transient forcing across Canada. The results show that land used for energy crop production increased of 27% in last decade, while summerfallow land declined to a low level. As a result, species diversity declined. Validation and calibration show that the model is capable of capturing essential dynamics of land use change and ecosystem functioning. Simulation results indicate that land for energy crop production will further increase in next decade in order to meet the requirement from bioethanol industry. Species diversity will decline as agricultural land use change. The impact of agricultural land use change on regional biodiversity is limited in a short term, but it will be strengthen in a long term.**

Index Terms **- energy crop, biodiversity, dynamic systems modeling, land use change**

I. INTRODUCTION

As a commitment to meet the Kyoto protocol, Canada's Government announced "The Ethanol Expansion Program". Bioethanol has been proposed to compensate greenhouse gas (GHG) emissions. This program is expected to increase Canada's ethanol production capacity. This increase in production capacity will support current and proposed programs for ethanol in gasoline and is an important step towards the Climate Change Plan for Canada target of having at least 35 percent of our gasoline contain 10 percent ethanol by 2010 [1]. Current production is about 200 million liters, while 7 percent of gasoline sold in Canada is currently blended with ethanol [2]. To meet this target, it required more energy crop for bioethanol. This is the driving force for growing energy crop for bioethanol. Currently, to use of bioethanol 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 bioethanol depending on factors such as: choice of biomass used to make the fuel (e.g. crop wastes, canola, soybean, etc.) and the manner in which crops are farmed (whether there is heavy use of pesticides and fertilizers, use of irrigation, etc.) [3]. Energy crops can create better wildlife habitat than food crops. Since they are native plants, they attract a greater variety of birds and small mammals than modern industrial food-producing farms. Compared to undisturbed natural habitat, energy crops are not as good for supporting biodiversity. But energy crop farms can be managed so as to be much closer to the natural world than industrial food- producing farms. Nonetheless, the environmental benefits of bioethanol hinge on whether energy crops are managed with sustainable agricultural practices. Just like food crops, they can be mishandled, with productivity increased by greater chemical inputs [4].

On the other hand, ecological problems are likely to arise if the cultivation of bioethanol products is pushed. In sum, pushing bioethanol not based on waste utilization would yield no positive environmental effects but merely shift environmental problems, e.g. emissions, to water, soil and biodiversity [5]. The potential impacts of land use on ecosystem functioning and biodiversity have received considerable attention during last decade, but it still lack adequate theories and models to predict and interpret such results. Thus the main objective of this study is to develop and test a dynamic systems modeling, called LCIB, for the assessment of the impact of energy crop on biodiversity. 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.

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II. MODEL DEVELOPMENT

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. A basic dynamic hypothesis linking species diversity to ecosystem structures and landuse dynamic behavior have been developed. The dynamic behavior of the system is generated by endogenous structures, and feedback loops to control in all system [6]. In ecosystem dynamics depends upon a combination a combination of their history and the current dynamics of their environment. The sources of biodiversity in agroecosystem in Canada include: landuse dynamic from energy crop, pasture, summerfallow and other crop land, ecosystem dynamic i.e. nutrient, biomass, natural consumer, organic matter in soil and decomposer. There are four major subsystems linking. The models use the species diversity and composition of ecosystem function as indicators of biodiversity change. The definition of landuse in this study modified from Agriculture and Agri-Food Canada.

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. 1.

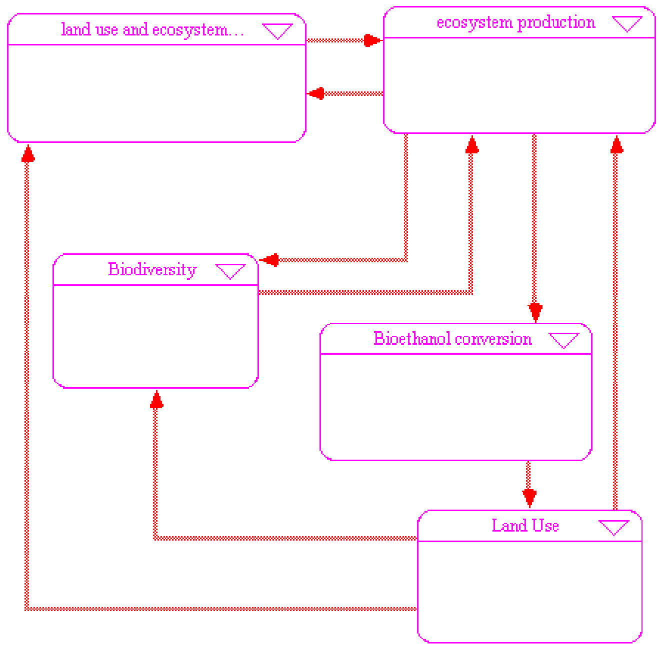


Figure1 Basic structure of LCIB

From Fig. 1, the first module is a landuse dynamic. The data used for the interchange among landuse types in Canada. The second module to assess the ecosystem functions in agroecosytsem. The underlying modelling approach is that only those relationship between energy crop and nutrient in soil that using for ethanol will be considered. The third module is the species diversity in agroecosytsem, including the loss/increase diversity, extinction/substitute, emergency rate, soil capacity and biomass. Species diversity related to the cultivation of crop biomass, including the production and use of fertilizer are computed. The fourth is the driving force of overall system that is bioethanol status. It then adds to model the supply of biomass needed to produce the bioethanol demanded under various scenario. The fifth is the requirement of each landuse types in term of resources usage i.e. organics matter in soil, nutrient, decomposer, natural consumer, etc.

A base case scenario models the continued use of energy crop in bioethanol. These model experiments were driven by historical time series and projected transient scenarios of species diversity. In what follows, this paper briefly describes the important processes and the structure in each module and displays the STELLA diagram. The model also attempts to demonstrate that the impact of energy crop on species diversity must be addressed simultaneously in studying sustainable development performance. The long-term effects of a huge over-energy crop are not to be taken into account in this model, since we consider that (1) the carrying capacity might not be overshoot and (2) the total area covered by forest cannot decrease. The details of each module are as following:

1. Landuse dynamics

In this study, the landuse dynamics system focused on four landuse types that can be exchanged with each other. The promotion of the production of bioethanol on set-aside land means the continuation of intensive agriculture, with its well-known impact on the environment (loss of biodiversity and organic matter in soil, etc.). From the model diagram (Figure 2), the flow showed the interchange among landuse types:

1. summerfallow (SF) is changed to pasture land (P);
2. summerfallow (SF) is changed to crop land (CL);
3. summerfallow (SF) is changed to othercrop land (OC);
4. summerfallow (SF) is changed to energy crop land (EC);
5. crop land (CL) is changed to summer fallow (SF);
6. crop land (CL) is changed to pasture land (P);
7. crop land (CL) is changed to crop land (CL);
8. crop land (CL) is changed to othercrop land (OC);
9. crop land (CL) is changed to energy crop land (EC);
10. pasture land (P) is changed to summerfallow (SF);
11. pasture land (P) is changed to crop land (CL);
12. pasture land (P) is changed to othercrop land (OC);

13. pasture land (P) is changed to energy crop land (EC); and so on.

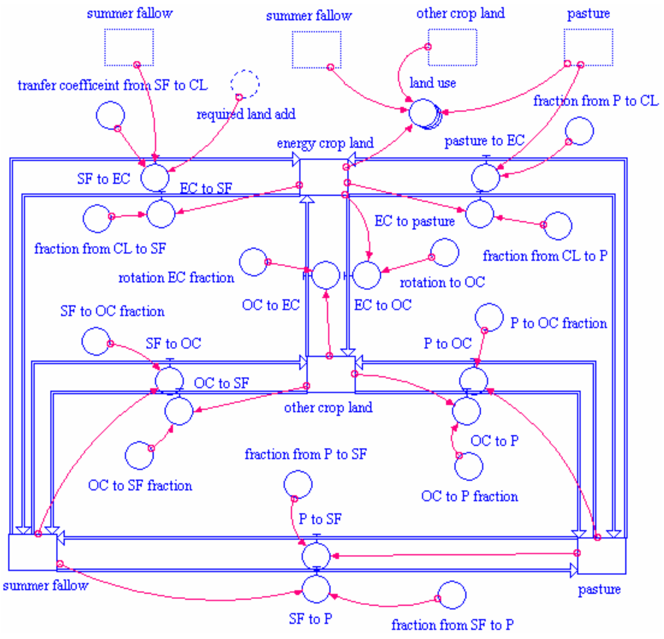


Figure 2. STELLA diagram of landuse

The energy crop land required takes into account landuse dynamics and time constrains for bioethanol conversion. When the energy crop pressure is very high, the simulation must show a progressive decrease of pasture and summerfallow area, which are replaced by energy crops.

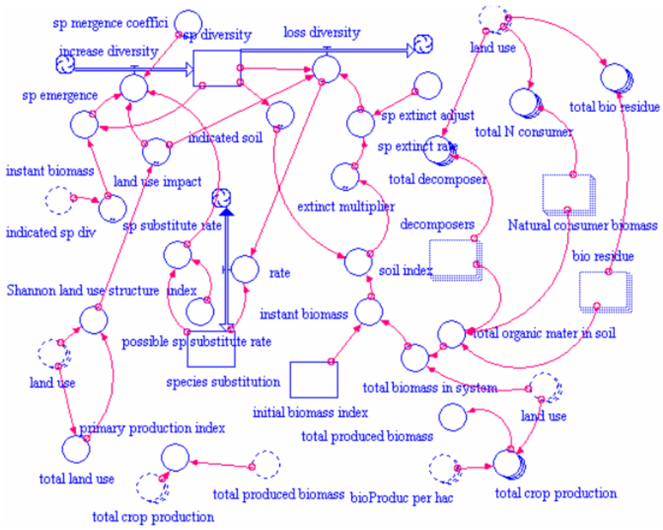
2. Ecosystem function

The ecosystem function module in LCIB includes nutrient, organic matter in soil and the residue as stated variables and factors of energy crop production from both energy crop and residue. In this study focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms (natural consumer biomass) and their environment, and among ecosystems. The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices. Ecosystem structure variables are most promising indicators of biodiversity because they can offer a lot of information on the state of ecosystems over large areas for relatively low effort. Many aspects of quality can be captured by identifying key-ecosystem structure variables which can indicate if the ecosystem is functioning correctly or not [7].

The functional processes of ecosystems, such as flow of physical and chemical matter, are subject to biodiversity dynamics. Species richness is usually considered a function of the diversity of habitats and the number of potentially available ecological niches. Owing to their biodiversity, ecosystem plays a role in the regulation the nutrient cycle, thus reciprocally controlled by physical, chemical and biological processes. The accelerating drive for efficiency and productivity gains to maintain Canada's biodiversity in agricultural area will continue to promote the non-economic benefits. This conflict will ensure that energy crop supply and demand factors will be of increasing prominence in the agricultural biodiversity over the next 10 years and beyond.

3. Bioethanol conversion

Bioethanol should now be recognized as the key resource element in the expansion plans of energy crop areas. In what follows, this paper briefly describes the important processes and the structure in each module and displays the STELLA diagram. The most important ones are agricultural products grown for bioethanol, as well as waste from the agriculture, and perhaps also byproducts in the future. The reality of energy crop land requirement is our overwhelming reliance on ethanol demand for ethanol. The essential change is to effect the transition from residue to fuels. The process of transition will have to recognize the inertia in government policy but the change itself will be evolutionary. The STELLA diagram (Figure 3) shows the ethanol target in 2010 is the major driving force to energy crop production.



* modified from the model of secondary autogenic grassland succession [8]

Figure 3 STELLA diagram of biodiversity

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4. Biodiversity

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, the disturbance of breeding places and natural plant societies, all contribute to the loss of biodiversity. From all, the STELLA diagram was developed to measure species diversity. The goal of this module is to reconsider the possibility of mathematically predictable diversity dynamics on evolutionary time scales. In this paper presents an analysis of diversity dynamics in a model. The analysis will show that diversity is equilibrial; equilibrium is maintained by the suppression of origination rates, perhaps through competition; there is no long-term trend in the equilibrium diversity level.

5. Landuse and ecosystem transit

This module explained the requirement of each landuse types in term of resources usage i.e. organics matter in soil, nutrient, decomposer, natural consumer, etc.

III. TESTING AND CALIBRATION

The assessment of biodiversity with results will be used to test and calibrate the methodology under study. In particular, it will be used to calibrate the coefficients used to determine the measures of biodiversity so that comparable data is produced. The calibration process of LCIB model: The historical data came from www.statcan.ca in the year 1991, 1996 and 2001. STELLA model can simulate data. The more energy crop area is, the less the other land areas are. If the governments would like to meet the target in 2010, they also need to take action to modify longer-term trends in landuse management for increase land for energy crop.

IV. SCENARIO ANALYSIS

Scenarios in this study are assumed that the total area of this study does not change. Landuse change from each other i.e. pasture to energy crop land and energy crop change to pasture; other agricultural land to energy crop land and energy crop land to other agricultural land, summerfallow (SF) and cropland to energy crop land and so on.

Scenarios

1. Base case
2. Base case + Bioethanol required land from summerfollow by ± 30%

The impact of agricultural land use change on regional biodiversity is limited in a short term, but it will be strengthen in a long term as shown in Fig. 4.

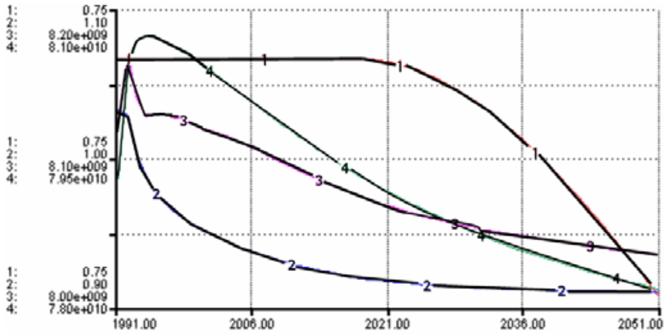

Figure 4 The simulation of species diversity in 10 years

From Fig. 4, it showed that biodiversity impact on energy crop production (1). The more energy crop, the less nutrient (2), biomass production (3) and organic matter in soil (4). However, simulation results indicate that land for energy crop production will further increase in next decade in order to meet the requirement from bio-energy industry. Agricultural ecosystem functioning index will decline as agricultural land use change. The impact of agricultural land use change on regional biodiversity is limited in a short term, but it will be strengthen in a long term.

V. RESULTS AND DISCUSSION

The only significant potential negative impacts are the use of agrochemicals, and changes to the ecosystem. These and other 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 make simple environmental impacts of bioethanol generated from energy crops, because the impacts are site and crop dependent. There is also limited experience of the cultivation and generation phases of the energy crops fuel cycle. The major environmental burdens are impacts from cultivation of the energy crop (use of agrochemicals, soil erosion and visual intrusion) and impacts on local ecosystems, etc.

This model does not predict a constant level of biodiversity for a certain combination of parameters, but rather than a pattern of fluctuations within limits establishes by the model of dynamic equilibrium. 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 for the dynamics and production of other functional groups. The greater biodiversity is more favorable to the production and stability of ecosystems. The productivity of ecosystem 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.

Based on our estimates and recognizing the inherent difficulties with imprecise data and the use of projections, the landuse vision for agriculture in 2010 appears to be achievable given potential 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 consent returns. Many are topics of this study that are not expanded listed as 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 impacts of energy crop for ethanol in terms of soil loss from agricultural chemicals would be considerable. The ecological function scenarios, soil properties, and potential crops and residue were prepared as common boundary conditions and driving variables for the models. The rate of soil erosion from managed lands depends on soil characteristics and the crop.

If the objective is to make agriculture more sustainable, it should be used for organic production or else be left fallow. Organic farming 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. In Canada, there are at least 50 different organic certification agencies. Organic grains and oilseeds grown in Canada include wheat (including durum), oats, barley, rye, buckwheat, flax, canola, and sunflower. The majority of Canadian organic grains and oilseeds are exported (as are conventionally produced corresponding crops). The organic grains go primarily to Europe and the US, and the majority of organically-grown oilseeds to the US. Estimating the size of the organic grains and oilseed industry is difficult, but likely it is less than 1% of the conventional crops. Organic crops command higher prices, typically 30% for grains and oilseeds, but the extent to which production can be made competitive with conventional cropping is unclear. The organic industry is expected to increase the share of the food retail market in Canada as consumers become increasingly conscious of the issues.

Wise manure usage is related to the subject of organic agriculture. Canada has a huge livestock industry (over 100 million hens and chickens; 111 million hogs; almost 5 million beef cows and over 1 million dairy cows; more than one-quarter of the nation's farms are beef farms), and consequently an associated production of manure. Manure is a valuable resource due to its nutrient content and soil amending properties. On the other hand, manure is expensive to transport, produces an odor that the public finds objectionable, and over-application may pollute surface and ground water. New crops and crop systems that utilize all this manure are extremely desirable, and are a priority in Canada.

VII. CONCLUSION AND RECOMMENDATION

Landuse change impact on biodiversity model (LCIB) is multidisciplinary fields as 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 land use change driven by bioethanol industry at a regional scale. The model, linking the bioethanol requirement, land use 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 connection between economics and environmental well being [9]. The model was validated structurally and behaviorally using the tests suggested by the literature, and then calibrated using last 10 years period Canadian agricultural land use and crop production data. It is to compare time-dependent ecological responses of land use dynamics and species diversity modeled to historical and projected transient forcing across Canada. The results show that land used for energy crop production increased of 27% in last decade, while summerfallow land declined to a low level. As a result, species diversity declined. Validation and calibration show that the model is capable of capturing essential dynamics of land use change and ecosystem functioning. Simulation results indicate that land for energy crop production will further increase in next decade in order to meet the requirement from bioethanol industry. Species diversity will decline as agricultural land use change. The environment within which models are developed must be suitable for multidisciplinary collaborative efforts. An ecosystem approach tries to include all possible ecosystem benefits so that trade-offs become efficient and sustainable. Dynamic modeling is a key to better land management in coordination with research institutions, begin to develop increasingly realistic models of national systems.

The impact of energy crops on habitat and biodiversity depends not only on the previous land use and cultivation but also on the nature of the energy crop. However, if the plantation displaced the permanent woodlands, forest area or other environmentally sensitive habitats, then 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. The guidelines for plantation developers can help to ensure that they are located in appropriate areas and that they are designed to maximise, as far as possible, habitat diversity. The impact of agricultural land use change on regional biodiversity is limited in a short term, but it will be strengthen in a long term [10].

Moreover, the monitoring changes in biological diversity at the species level essentially entails in 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. Many shy away from trying to seek solutions now, relying on scientists to invent new technologies to solve the problems at some time in the future. 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 or social welfare. The focus concept of sustainable agriculture benefits through higher crop yields, improved soil quality and agroecosystem diversity.

Canada is also developing the knowledge-gathering, integration, and dissemination tools and additional partnerships necessary for the application of an ecosystem approach to resource management. We are learning how to organize ongoing and future initiatives through trial and error and the sharing of best practices. The concept of sustainable development necessarily requires the ecosystem-based approach to exploitation of the 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.

VIII. ACKNOWLEDGEMENTS

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