Multi-scale modelling as a tool for sharing the perspectives of researchers, practitioners and farmers on beneficial management practices to be adopted in an intensive agricultural watershed

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Abstract

Canadian agricultural production systems are facing issues related to maintaining high crop yields and profitability while adopting beneficial management practices (BMPs) that mitigate their impact on the health of the environment. Since 2014, Agriculture and Agri-Food Canada (AAFC) has been collaborating on the development of an open innovation platform, namely the "L'Acadie-Lab" living laboratory, initiated by an interactive community of farmers, practitioners and researchers to increase the adoption of BMPs in the L'Acadie River watershed, in southern Quebec' Canada. So far, workshops were held featuring farmers, practitioners, scientists and other stakeholders. These workshops have revealed a disconnect between farmers' expectations and research organisations' ability to provide a consistent array of practices and knowledge. To get new knowledge and technology adopted, consistent choices between various practices that interact on a range of spatial and temporal scales have to be proposed to the users and the economic and ecosystem benefits have to be demonstrated. In response to these issues, the authors propose the development and use of a participatory modelling approach as a tool for sharing the perspectives of researchers, practitioners and farmers on innovative practices to be adopted. The approach links the knowledge of researchers and certain modelling tools at the plot level or the farm level with ecosystem services simulation models at the landscape level to produce quantitative or semi-quantitative results. Farmers and advisors will play a special role in defining the scenarios to be simulated to ensure that their situations and concerns are reflected and to increase the commitment to innovation.

Keywords: beneficial management practice, open innovation, knowledge and technology transfer, participatory modelling, intensive agricultural watershed.

1. Introduction

1.1 Issues for the Canadian agriculture

The agricultural systems in eastern Canada and notably Québec and Ontario are dominated by intensive crop production, mostly maize and soya, which use large quantities of inputs. These systems have many environmental impacts such as water quality deterioration, loss of biodiversity, soil erosion, deforestation and greenhouse gas emissions.

Research and development agencies have developed and promoted beneficial management practices (BMP) for more than two decades. In particular, advances have been obtained in knowledge pertaining BMPs related to fertilization, soil conservation practices, hydrological infrastructures, and integrated pest management (AAFC, 2015). However limited success has been seen in their implementation in farmers' fields (Groulx-Tellier, 2012; Bibeau and Breune, 2005). In fact, the implementation of the BMPs faces two significant issues in Quebec:

- The difficulty in getting a critical mass of farmers to participate, in particular for developments that have an impact on the landscapes.
- These programs often fall short in sustaining the adoption of the BMPs.

Current programs of development of the BMPs have made it possible to favor the adoption of agro-environmental practices among those farmers who were already the most convinced of their importance (pro-environment attitude). A large part of farmers that have a less environmental friendly attitude thus remains to be convinced and the extent of their participation in these programs is therefore critical for the success of implementation of the BMPs. It is also often observed that once the financial support has come to an end, the mobilization of the agricultural community starts to weaken. In other words, the developments that are done in the field are not all maintained or preserved once the project is over. This situation calls for a new way of thinking the transfer of BMPs to the farming community. In fact, the most recent literature supports this need for a shift in thinking on the research-development-transfer continuum.

1.2 New ways of seeing innovations

Innovation theory generally distinguishes two categories of innovation processes (Leeuwis and Aarts, 2011): linear processes, most commonly given by the experts or by the technology to be promoted, and systemic processes. The theoretical conception of innovation that is most familiar to governments is the top-down approach, where innovation follows a linear path from the initial idea to adoption by the end user, who is a receiver of information (ENRD, 2013). Initially developed for the transfer of so-called "hard" technologies and marketable products, this type of linear process is today considered inadequate for knowledge and technology that concern the introduction of beneficial management practices and sustainable production systems in the farming landscape (Dolinska and Aquino, 2016; ENRD, 2013; Anandajayasekeram, 2011). This inadequacy stems from the fact that agriculture is based on management decisions made in a complex context of biophysical, ecological and socioeconomic interactions, and that the knowledge and technology cannot be directly adopted, each farmer has to adapt them to his specific context (Martin et al., 2015; McIntyre et al., 2009). Moreover, the public research and development organisations tend to produce individual and partial sets of knowledge and technology (silos), which the farmer or even the agricultural advisor finds difficult to integrate (Anandajayasekeram, 2011). Finally, the success of linear innovation is very dependent on the capacity of research to design tangible results that are relevant for users (ENRD, 2013). In a system where local conditions are preponderant factors in the adoption of knowledge and technology, the innovation approach must sometimes incorporate the contribution of the users into the creation process, for which the linear model was not designed. Esparcia (2014) frames the importance to innovation of combining local and expert knowledge, with a wider network of support from the public sector.

Systemic innovation models were proposed in the early 1990s to take into account the fact that in agriculture, innovation does not arise from a single source of knowledge, but from multiple sources (e.g. researchers, practitioners, users, NGOs, etc.) and that every generation of knowledge and technology occurs in a certain political, economic, agroclimatic and institutional context (Anandajayasekeram, 2011). Today, Canada's strategy "Seizing Canada's Moment: Moving

Forward in Science, Technology and Innovation 2014" (Government of Canada, 2014) recognizes that "innovation is a complicated process that is neither defined by a simple formula or playbook, nor easily measured," and that sometimes, "innovation comes directly from advances in science and technology, but it can also stem from other sources." According to Berthet et al. (2015), innovation in such an agro-ecosystemic context will depend on changes in the nature of the knowledge, which will be both agricultural and ecosystemic, and on the social interactions inherent in the reduction of the knowledge by the various stakeholders, which suggests a need for a participatory approach.

Following these statements, the authors of this paper have initiated a new dynamic in a region situated in the South West of the Québec province, in a river basin that concentrates the environmental issues related to agricultural systems impacts. This dynamic takes the form of a living laboratory that is presented in the next section.

2. The Living Lab approach

2.1 Fundamentals of Living labs

Since 2014, the authors have been collaborating with agricultural and environmental organizations of the L'Acadie watershed on developing a knowledge and technology transfer platform (Umvelt, 2015; Gariépy et al., 2015). This living laboratory, called L'AcadieLab, requires the commitment of all actors, and seeks to address the issues of rehabilitating agroecosystems and creating attractive living environments within the territories with intensive farming.

The L'AcadieLab relies on an open innovation approach, inspired by living laboratories and involving a community of agricultural producers, practitioners and researchers. This approach:

- Is based on the process of co-creation and experimentation of new agro-environmental practices with the end users (the farmers) in real conditions (a specific watershed).
- Is carried forward by the users. It involves the farmer both as stakeholder in the processes of co-creation and as beneficiary of the positive outcomes of these processes.
- Is based on a collaborative partnership that brings together the whole agro-environmental innovation chain from the research to the extension and professionals of farming.

Through this approach, the knowledge provided by the farmers is every bit as important as the knowledge coming from the other stakeholders (the actors in the agro-environmental innovation chain and the researchers for example). It is, above all, a way of being and doing in the project. For example, instead of proposing a priori a new integrated development model for watersheds, it offers an opportunity to establish a dialogue among existing models, and attempts to create synergies among them, in order to ultimately arrive at a new or combined approach and at development tools integrated by the co-creation among the stakeholders.

2.2 L'Acadie River watershed

The L'Acadie River flows north over 82 km in the Montérégie region, on the south shore of St. Lawrence River, in Quebec, Canada. Its source is located near the municipality of Hemmingford (45.038N/73.558W). It runs north through Napierville and L'Acadie to its mouth at Chambly Basin (45.476N/73.287W). It is the main tributary of the Richelieu River, which is home to more than 50 species of fish, some of which are considered threatened or endangered, such as copper redhorse, river redhorse and lake sturgeon.

The L'Acadie River flows through a number of small towns as well as agricultural and forest areas (Fig. 1). Its drainage basin covers an area of 41,336 ha, including 30,884 ha (75%) under cultivation, mainly grain corn, soybean and vegetables. More than 10,000 ha are cropped under the supervision of local agri-environmental advisory clubs. An AAFC experimental farm also operates in the watershed. The area has major issues pertaining to surface and subsurface water quality, soil conservation as well as habitat rehabilitation.

Considering the type of land use and intensive anthropogenic activity within the watershed, as well as the commitment by farmers to agricultural beneficial management practices, the L'Acadie River watershed offers a suitable context for the implementation of a living lab aimed at improving the development and adoption of knowledge and technology.

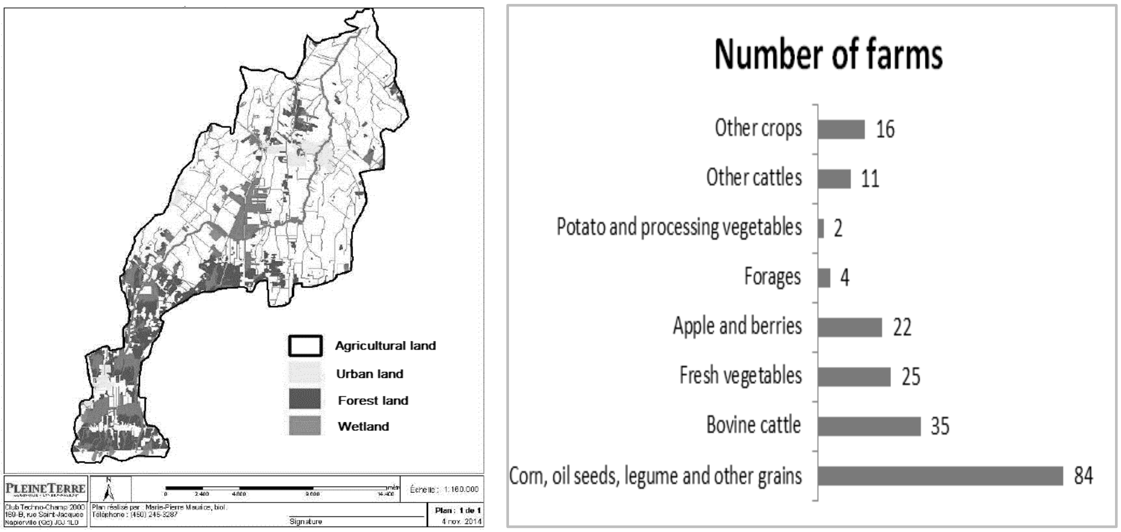

Figure 1. L'Acadie watershed land use and number of farms per category of production

2.3 Activities conducted and results achieved in the L'AcadieLab so far

In 2014-2015, a series of meetings were held to lay the foundations of collaboration and to identify BMPs to be implemented. Researchers, local partners, community stakeholders and 55 farmers have participated in this start-up and mobilization phase. Ten BMPs with the potential to maximize the positive environmental benefits of the projects to rehabilitate agricultural systems have been listed and analyzed collectively to identify the most promising. It is on this basis that the cycle of co-creation and exploration has been developed. The following paragraphs highlight the gap between the farmers and the researchers' perceptions with regards to the gain and effort pertaining to specific BMPs.

2.3.1 Farmers' perception of the usefulness and credibility of the BMPs

Figure 2 illustrates the evaluation done by local agriculture stakeholders (mainly farmers and agricultural advisors) of the effectiveness of the proposed BMPs. In the opinion of the participants who were invited to evaluate the proposed BMPs, it seems that measures such as the riparian buffers, the two stage channel and the wet-retention ponds are perceived as unattractive measures. These measures require an effort on the part of agricultural producers that is considered to be excessive in relation to their perception of the environmental gain and of the satisfaction of their needs that such measures could produce. On the contrary, integrated pest management, direct seeding and controlled drainage seem to be of proven value in terms of gain. Moreover, SCAN (a tool for optimising fertilization) and cover plants seem to be less difficult to adopt for the producers. Apart from the evaluation by the local agriculture stakeholders, what we observed was their high capacity to establish a consensus on their perceptions of the potential gains and required efforts associated with each practice.

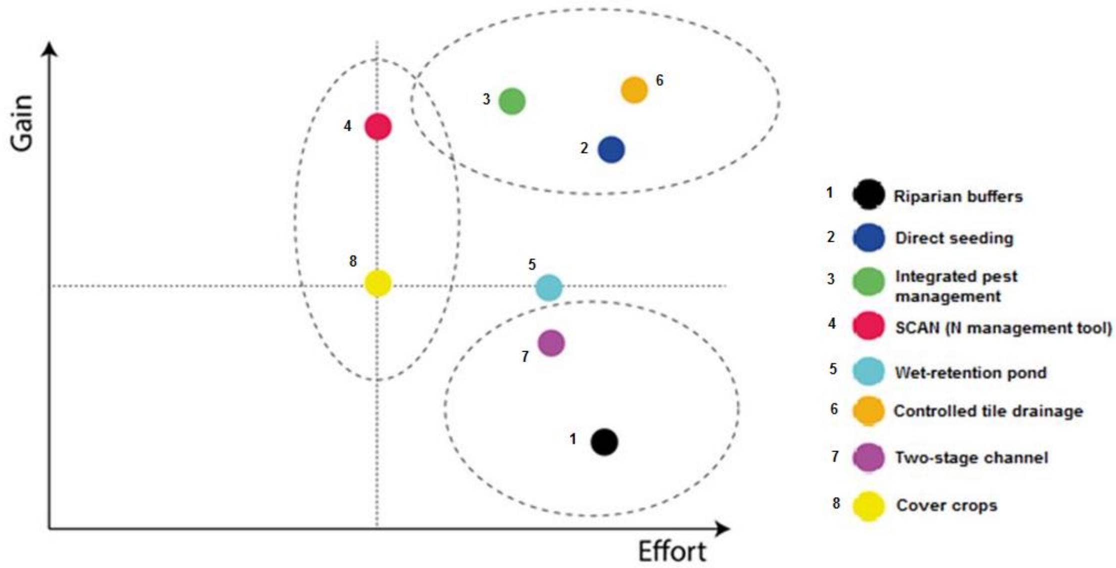

Figure 2. Perceptions of local agriculture stakeholders of the effectiveness of the proposed BMPs. Each point represents the consensus obtained among farmers, agricultural advisors and stakeholders participating to the workshop.

2.3.2 Support of researchers for an open innovation approach: a challenge yet to be met

A similar exercise was carried out with the researchers from different research institutions that could be involved in the future of the L'AcadieLab. In figure 3, each point represents the vision expressed by one or more researchers. Although the same exercise was proposed to the farmers and researchers, a consensus was not reached within the community of researchers concerning the potential gain and effort that the implementation of the BMPs would require in real conditions.

There is therefore a clear difference of perceptions between the farmers and local stakeholders, and the researchers. For example, the riparian buffer is seen by local participant as a BMP with a low potential gain while the researchers considered that the gains related to the adoption of this measure would be medium to high. To get new knowledge and technology adopted, consistent choices between various practices that interact on a range of spatial and temporal scales have to be proposed to the users and the economic and ecosystem benefits have to be demonstrated. Further information about the BMPs, their usefulness, advantages and drawbacks, and contribution to the sustainability of the farming systems and of the region is needed.

Consequently, even in a collaborative approach are there major challenges that lie ahead if we want farmers to adopt innovative practices stemming from research, including: building the capacity of stakeholders to make consistent choices between various practices that interact on a range of spatial and temporal scales; and establishing methodologies for assessing the economic and ecosystem benefits for farmers and society in adopting new knowledge and technology. In response to these issues, the authors propose the development and use of a participatory modelling approach as a tool for generating the needed knowledge and for sharing the perspectives of researchers, practitioners and farmers on innovative practices to be adopted.

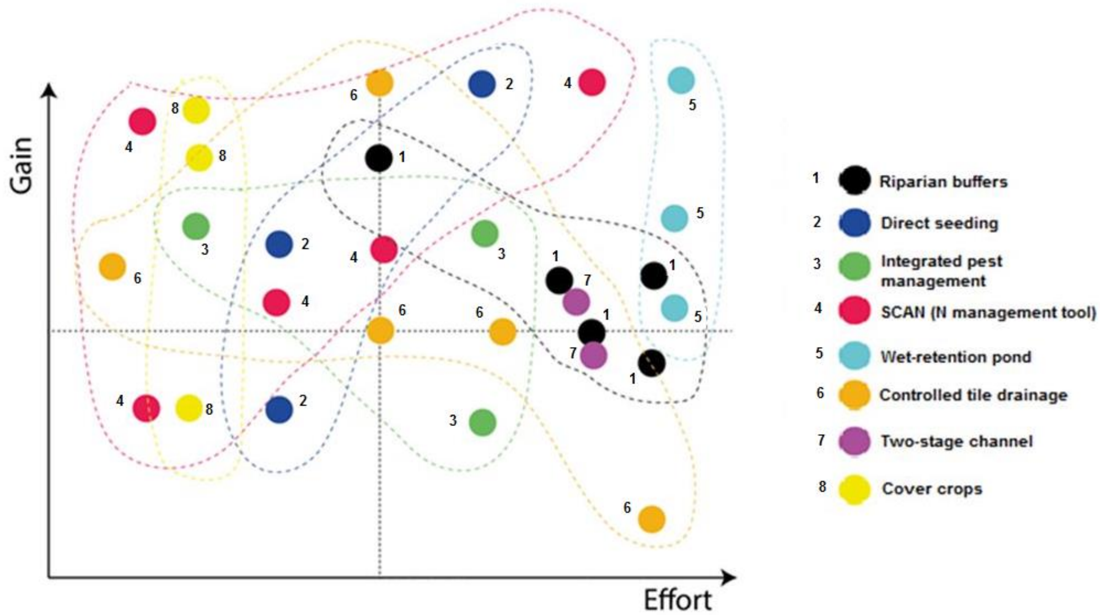

Figure 3. Perception of researchers questioned about the effort and the gain produced by the BMPs. As the researchers did not reach a consensus, their different visions are represented (each vision is represented by a point).

3. Proposition of a framework for scenario development

3.1 Rational

Through the development of participatory modelling, the project team is seeking to address three major scientific and management issues relating to the establishment of the L'AcadieLab and to the BMPs:

- The improvement of the capacity of the stakeholders to make a coherent choice among various scenarios for adopting the BMPs introduced at various spatial scales (parcel, farm, landscape or watershed) and temporal scales (e.g. impact of climate changes, changes in markets).
- The development of a methodology for evaluating the consequences of adopting these BMPs for the farmer and society, in particular through indicators of sustainability, which will immediately be used to evaluate the sustainable nature of the systems and modes of production.
- The acquisition of a scientific understanding of how to optimise and quantify ecosystem services as a result of the possible introduction of new knowledge and technology into agricultural systems.

Many methodologies have been developed and implemented to bring together the actors in research and development projects (Bos et al., 2009; Neef and Neubert, 2010). Participatory approaches, in partnership, possibly with the creation of multi-actor platforms, have been imagined and tested for the diagnosis of existing and innovative systems and the co-construction and evaluation of scenarios (Giampietro, 2003; Kok, Biggs et al., 2007; Etienne, 2011; Meynard et al., 2012; Bewsell, 2013). The farmers and local actors of the L'Acadie River watershed, AAFC researchers and partner institutions will also be closely associated with this work of evaluating innovative systems and formalizing possible futures, for at least three reasons:

- In a territory, the actors bring knowledge of the biophysical and socioeconomic characteristics of their environment, which are relevant for evaluating agricultural systems (Scoones and Thompson, 1994), and for co-creating innovative systems (Salembier et al., 2015).
- Their knowledge can influence the choice of evaluation criteria, and even bring in new criteria and act on the definition of the level of detail necessary for quantifying indicators, so that they will put their trust in the indicators and be able to use them for negotiations or decisions (Delmotte et al. 2016).
- In a territory, some actors (for example, agriculture advisors, farmer associations' representatives) have the capacity to make the changes required to improve the economic and environmental performances of the agricultural systems (Martin et al., 2015).

For these reasons, our plan is to use, jointly with the actors, a diversity of models to design and assist developments of agricultural systems. The simulation models will be used to evaluate the anticipated consequences of the transfer of knowledge and technology and of projected innovation in terms of the sustainability of the agricultural systems and of goods and services offered by the agricultural territory of the L'Acadie River watershed. However, so that the knowledge and technology can be jointly developed and shared with the local actors (e.g. farmers, agriculture advisors, farming and environmental associations), it is appropriate to mobilize them through a participatory approach.

3.2 Methodological approach

The project's methodological approach consists of associating the knowledge of the scientists and cropping and farming modelling tools, with one or more simulation models of ecosystem services on the territorial scale.

The implementation of the methodology will involve two phases: (1) an initial phase of diagnosis, making use of the farming system sustainability analysis method (the IDEA method – Vilain, 2008), in order to better understand and prioritize the issues that concern the agricultural systems in the region; and (2) a second phase, more forward-looking, that will use the models to develop and assess scenarios.

3.2.1 Initial diagnosis

In recent decades, many conceptual frameworks have been developed for evaluating the sustainability of agricultural systems on the basis of multi-criteria evaluation (Munda et al., 1994; Lopez Ridaura et al., 2002; Parra-López et al., 2009; Koschke et al., 2012). However, in many cases, these frameworks have a primarily scientific perspective, and have not been designed in terms of field studies operationality, for and with the local actors in agricultural systems. However, some recent studies, in particular in Canada (Bélanger et al., 2012; Thivierge et al., 2014) and in Europe (Delmotte et al., 2016; Sadok et al., 2009; Barbier and Lopez-Ridaura, 2010; Zahm et al., 2015) have proposed methods and tools for adapting these frameworks to particular contexts.

In the first phase of the project, it will therefore be appropriate to adapt the existing conceptual frameworks to the situation of the L'Acadie River watershed. To do this, the above-mentioned works will be mobilized. In particular, the potential of the IDEA method developed in France and of other similar approaches such as the DELTA method (Bélanger et al., 2012; Thivierge et al., 2014) will be analyzed. IDEA is a method for diagnosing the sustainability of farming operations that is already operational. Its implementation also encourages thinking about the criteria and indicators of sustainability that must be adapted to the context of the farming operations and of the study region. This method has the advantage of very quickly providing a result for the participating farmer and, by carrying out some diagnosis, to establish a summary diagnosis of the current situation and major issues for the region.

It will therefore be adapted to:

- Do a diagnosis of the current situation, which will be used as a benchmark of comparison with the scenarios where the BMPs would be implemented. This step will also make it possible to complete the existing data on the farming operations, with a view to modelling them.
- Reflect collectively on the major issues relating to the sustainability of the agricultural systems of the L'Acadie River watershed that it will be necessary to take into account in the various modeling tools available.

This implementation of a multi-criteria evaluation method will be part of the on-going work in the basin of the L'Acadie River using the participatory approach. Therefore this shared diagnosis will be constructed collectively. This approach should help to define the indicators of sustainability to be quantified by models or, as the case may be, to be further developed in a more qualitative way.

3.2.2 Modeling and scenario assessment

In the second phase, the simulation of scenarios for the adoption of practices will provide food for thought for participants in the L'AcadieLab platform concerning the advantages and disadvantages of the various innovations in terms of the sustainability of the systems and the ecosystem services offered by the farming landscape. Workshops will be organized in order to co-construct, with the local actors, scenarios for developing the region’s agricultural systems, and for thinking about BMPs and other innovations that could be implemented in the context of these scenarios and the farming operations of the region. The use of modelling will also make it possible to take into account the impact of climate change scenarios on the choice of practices and agricultural systems. Two models will be considered for agricultural systems analysis: STICS (multidisciplinary simulator for standard crops) and IFSM (Integrated Farm System Model). Moreover a model of ecosystem services will be used at the regional level. The models are described in the next sections.

3.2.3 Modelling agroecosystems at the level of the parcel and the farm

Simulation models of agroecosystems are particularly useful tools for evaluating the impact of agricultural practices and climate changes on the operation and performance of agricultural systems, and thus for supporting decision-making at the farm level. These models operate on different spatial scales, from the individual agricultural field to the whole farm or watershed. The crop model STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard [multidisciplinary simulator for standard crops]) simulate the growth of plants and the carbon, nitrogen and water balances of a field (Brisson et al., 1998; 2008), taking into consideration the interactions among the different modes of crop management, the soils’ properties and the climate. This model has recently been calibrated and validated to simulate growth of several field crops (spring wheat, corn and soybean in particular) in Canada and more particularly in the Montérégie (Jégo et al., 2010, 2011). STICS has also been coupled with a snow cover simulation model (Jégo et al., 2014) in order to improve prediction of water and nitrogen balances in fields under the climatic conditions of Eastern Canada (short growing season and long snow cover period).

On a larger spatial scale, the IFSM model (Integrated Farm System Model; Rotz et al., 2015) has been recently adapted as well, to simulate the growth of the main perennial and annual crops used in Eastern Canada (Jégo et al., 2015). This model allows simulation of the agronomic (productions), economic and environmental (water, nitrogen, carbon and phosphorus) balances of a farm. Several dairy farms representative of three regions of Canada (including two in Quebec) were defined in the model, in a previous project. Although the IFSM was initially developed to simulate the operation of dairy farms, the most recent versions of the model also make it possible to simulate the farms involved only in producing field crops, which are present in the northern part of the L'Acadie watershed.

3.2.4 Modelling ecosystem services

Evaluating the consequences of developing innovations on the scale of a farming landscape or watershed makes it possible to take into account sustainability issues other than those evaluated at the level of the field and individual farm (Mitchell et al., 2015). Some aspects of the impact of agriculture on the environment can only be measured and quantified at these scales. The concepts of ecosystem services aim to evaluate the benefits derived from the operation of the ecosystems. Use of these concepts in connection with agricultural systems is recent, and is now the subject of many pieces of research work, which aim in particular to produce the tools required to quantify these ecosystem services (Dupras et al., 2013). A model was developed to allow evaluation of ecological services at the level of the territory (Mitchell et al., 2015). This model makes it possible to evaluate, in addition to supply services (agricultural production, forest production), regulation services such as pollination, the natural regulations of the predators of crops, the quality of water or storage of carbon in forests, and also such sociocultural services as the esthetic quality of the landscape or the region's farm tourism potential. This model has been developed for the territory of la Vallée du Richelieu (RCM), which is geographically a very close neighbour to the watershed of the L'Acadie River. This RCM has characteristics that are very similar, in terms of land use, to those observed in the L'Acadie River. It will thus be possible to use this model in connection with the project, to support decision-making for the adoption of BMPs and production systems.

4. Conclusion

An open innovation platform, the "L'Acadie-Lab" living laboratory, has been instigated in 2014 by an interactive community of agricultural producers, practitioners and researchers to increase the adoption of beneficial management practices (BMPs) in the L'Acadie River watershed, in southern Quebec, Canada. A gap has been observed between farmers' expectations in terms of economic and ecosystem benefits of BMPs and research organisations' ability to provide a consistent array of practices that interact on a range of spatial and temporal scales. In response to these issues, the authors propose the development and use of a participatory modelling approach as a tool for sharing the perspectives of researchers, practitioners and farmers on innovative practices to be adopted. The approach links the knowledge of researchers and certain modelling tools at the plot level or the farm level with ecosystem services simulation models at the landscape level to produce quantitative or semi-quantitative results. Simulation models will be used to evaluate the anticipated consequences of the transfer of knowledge and technology and of projected innovation in terms of the sustainability of the agricultural systems and of goods and services offered by the agricultural territory of the L'Acadie River watershed. Farmers and advisors will be mobilized through a participatory approach and will play a special role in defining the scenarios to be simulated to ensure that their situations and concerns are reflected and to increase their commitment to innovation.

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