Can We Measure Resilience? Reducing Agriculture's Vulnerability to Climate Change

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What is Resilience?

Over the last decade, researchers and policy-makers have been making considerable efforts to address and monitor the vulnerability of our society and the natural environment to climate change. At the early stages, the main focus was on risk-reduction measures. Next, work shifted to identifying direct responses to climate impacts, such as adaptation actions, to reduce vulnerability and, if possible, explore benefits. Recently, attention has moved beyond identifying specific adaptations to building resilience to ensure that people, communities, sectors and nature have the capacities to respond to whatever stresses arise.

Although resilience has been defined in many different ways, it generally refers to "the capacity [of a system] to absorb a shock" (Bousquet et al., 2016) as well as the ability to develop capacities to prepare for, cope with and adapt, and also potentially transform (Berkes, 2007; Schwarz et al., 2011). While the concept of resilience makes sense intuitively, it is challenging to bring together all elements of the system, such as the economy, society and environment, in a way to identify:

1. What makes the whole complex system resilient
2. What elements of the system need to be strengthened
3. What elements might undermine resilience

To make the concept of resilience easier to incorporate in policy-making, indicators can be used to provide a snapshot of key trends to describe the resilience within a particular system or sector.

In this brief, we explore the resilience measurement in agriculture and provide a list of indicators based on extensive collaborative research with policy-makers, academia and representatives of relevant agencies in Ontario.

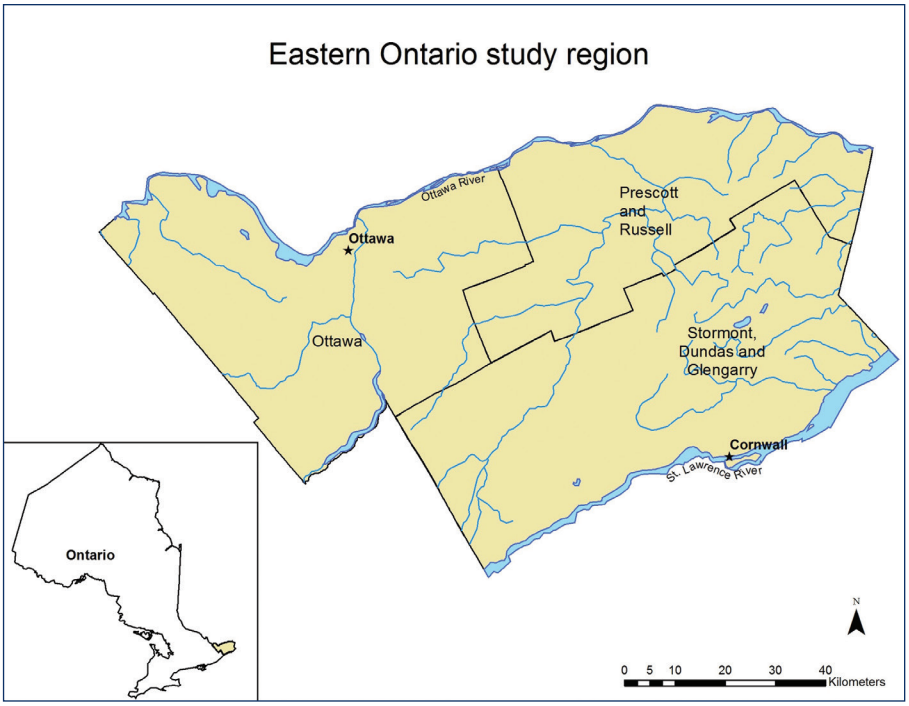

Figure 1. Study Area

The study is located in the eastern part of the Province of Ontario, Canada. The region is centred on the agricultural production of rainfed crops with high potential vulnerability to climate change and other challenges, such as a relatively low level of competitiveness of farms, ageing population, and declining infrastructure and environmental systems.

What Are Resilience Indicators?

Indicators are a critical part of the toolbox policy-makers can use to diagnose, develop and assess planning efforts. Two important uses for indicators are in:

i) Identifying specific vulnerabilities and gaps in resilience with regard to a specific objective, which allows targeted policies to be defined

ii) Evaluating the effectiveness of adaptation actions or programs to achieve greater resilience

In this context, resilience indicators are similar to those that assess vulnerability and adaptive capacity, but with the major difference that they consider socioeconomic systems to be dynamic and interactive. This implies that attention needs to be devoted, for example, to measuring the effectiveness of collaboration between different agencies, potentially through learning from climatic and non-climatic signals and the ability to revise plans and actions based on these signals. This then expands the view of impacts to a more holistic view, thus increasing relevance to governance, policy and planning (Tyler & Moench, 2012; Bizikova et al., 2015). Resilience-based approaches have been applied in urban areas, but they have yet to be applied to other sectors such as agriculture. Within the agricultural sector, specific indicators focus on the status of soils, planted crops, yields, infrastructure, financial performance, farmers' livelihoods and adoption of farming practices.

How Were the Indicators Selected in this Study?

Describing the Regional System

A framework was used to define the integrated system components in the study area (Figure 2). This system was developed based on input from over 100 experts representing local, provincial and federal government and non-government agencies in agriculture, environment, rural development and health to identify potential impacts of concern. Both external and internal drivers were considered, including climate change. Using the experts' feedback, we delineate categories of activities and identify the principle pathways of both effect and interaction. This also helps position the agricultural production systems within a broader socioeconomic context. In this way, each of the categories—such as regional drivers, different types of farmland production activities and diverse primary outcomes within the system map—came to represent a source of resilience.

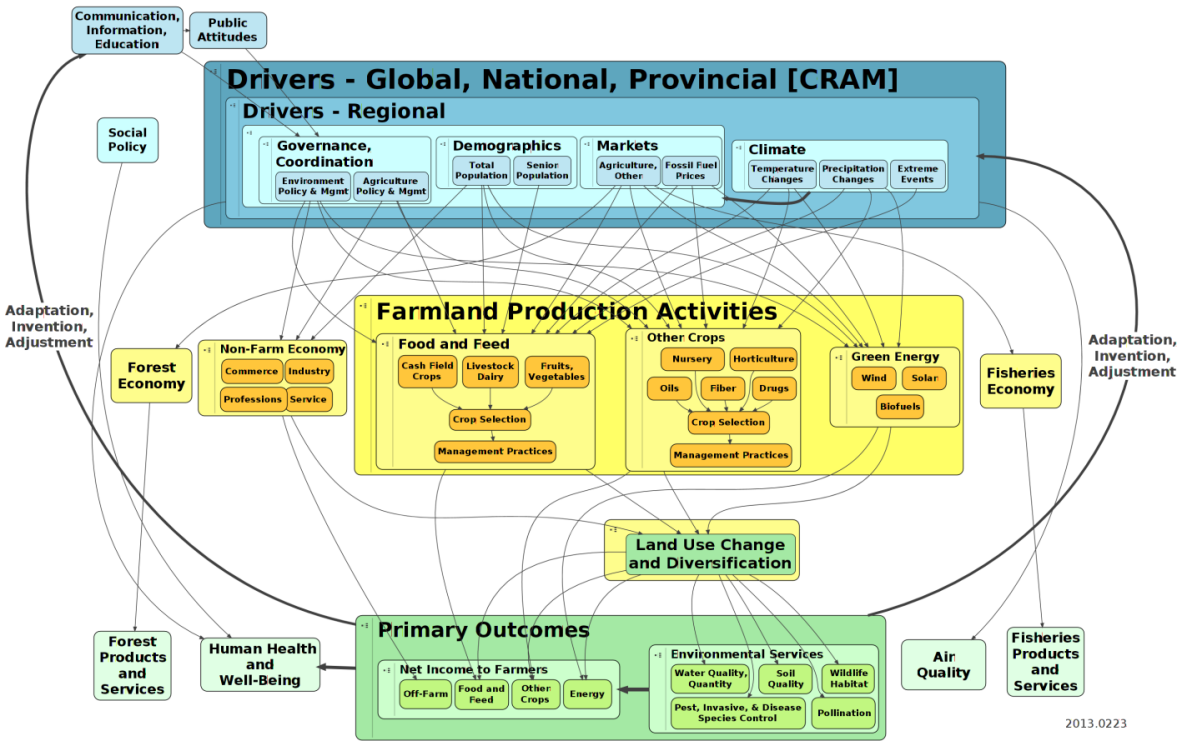

Figure 2. **Systems diagram showing key drivers and their pathways of influence**
Source: Waldick et al., 2016

Indicator selection

- A literature review established a reference database focusing on peer-reviewed literature and grey literature published by major international and national agencies such the European Environmental Agency, the U.S. Environmental Protection Agency, the UN's Agriculture and Food Organization, and Agriculture and Agri-food Canada. Potential data sources and thresholds were documented.
- The importance and relevance of the indicators to stakeholders was established using an online survey of over 80 respondents and a follow-up series of focus group meetings with over 50 stakeholders representing sectoral and thematic areas from three levels of government as well as non-governmental agencies.
- The final set of indicators was selected to describe the specific priority issues identified by stakeholders. In some cases, indicators from the initial literature review set were removed, while others were added. Indicators with promise but for which data availability is unknown in the study region were included as "optional" in the indicator system, as these may be feasible elsewhere in Canada.

Resilience Indicators for the Agricultural Sector

Thirty-six indicators were identified within six themes: climate change, population, farmland production activities, market and economy, rural infrastructure and natural environment. Indicators were advanced from the more traditional measures of the environment or society—like number of hot days or average rainfall and number of people employed in agriculture—to creating regionally meaningful changes in the timing, extent or features of impacts or outcomes. This tailoring of indicators allows different elements of the system and their relationships to be considered in terms of their direct or indirect contributions to resilience in the studied area.

Climate change impacts as well as other stressors have the potential to affect farm or family income in many ways: direct crop losses from extreme heat, drought, high precipitation, storms, flooding or wildfire; income losses due to working conditions; and/or potential increased costs to producers and households in order to ensure acceptable water quality or quantity (Reid et al., 2007; Lemmen, Warren, & Lacroix, 2008; Warren & Lemmen, 2014). Income stability issues for farmers also include off-farm income sources, levels of debt and crop insurance coverage.

Given the importance of agriculture in this region, as in many parts of Canada, the core part of the indicator set includes farmland production activities (and related land use change and diversification of both plant and animal production). Farmland activities, defined in terms of the risks they create or how they improve resilience, include production, infrastructure and management strategies. For example, the portion of farms with air conditioned barns can be used to reflect the ability of farmers to cope with extreme heat, both for their livestock and themselves.

The results of this system-based indicator approach, moving beyond a narrow focus on the agricultural sector, points to the need for a cross-sectoral effort in monitoring climate change impacts and other potential risks to strengthen resilience in rural areas.

Table 1. **Overview of suite of indicators within six themes**

Climate change	
What specific climate change features undermine resilience?	Changes in growing season; late spring frost; extreme heat; heat and wet spell duration; drought frequency and severity; deficit and excess water
Population	
What are population characteristics that can undermine resilience?	Agricultural producers as proportion of total rural population; rural inhabitants as proportion of total regional population; age of farmers; share of rural population more vulnerable to climate change due to age, poverty and location limiting access to basic services
Farmers and farmland production	
What farm practices can be a source of resilience?	Yearly agricultural output compared with long-term average; mix of crop type (perennial versus annual); proportion of farmland under conservation/no-till/ rotational grazing; livestock density; portion of farm infrastructure in flood-plains; portion of land with tile drainage; portion of barns with air-conditioning; manure management strategies
Market, Economy	
What are the characteristics of the farms with impacts on resilience?	Portion of farms with off-farm income; small and medium farms with insurance coverage; level of debt per farm type; GDP in rural areas; relative shares of small/ medium/large farms
Rural infrastructure	
What is the condition of the infrastructure to support resilience?	Portion of population with small/private drinking systems; frequency of drinking water shortages or contamination; road density in the flood plain; age and condition of the infrastructure; access/density of health emergency systems
Natural environment	
What are the critical features of the environment that can support resilience?	Species range shifts (e.g., hantavirus, invasive); erosion risk; watershed buffer zone; undisturbed buffer zone, rate of reforestation and deforestation; rural land management and species biodiversity

Do We Have the Data?

Data availability is an important criterion in considering the feasibility and suitability of each indicator in the set. Of the 36 indicators, approximately half could be adopted readily due to easy access of available data such as indicators on climate change, population and farm size, and income (Table 1; Figure 3). For the remaining indicators, data were either missing or could require considerable additional processing because of the format of the data before being suitable for use. One problematic information gap could be in accessing detailed farm production and economic data. Previous research has found that government statistical information about farms is becoming more difficult to analyze (Poon & Weersink, 2014). On the other hand, improved collaborations with universities for data sharing has been achieved, increasing access to more extensive and detailed data on things like wildlife species range shifts and rural land use. Combining data from different sources is also important; however, in many cases, data required to calculate some of the indicators has only been collected in the form of case studies, thus limiting values to selected farms within the region.

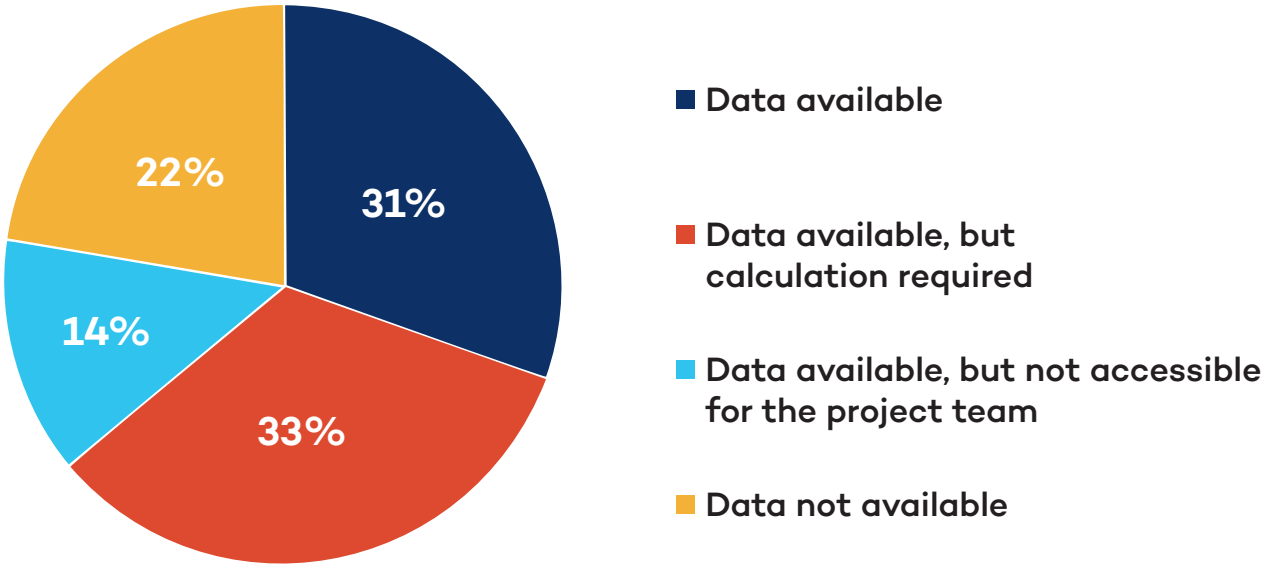

Figure 3. Data availability for selected indicators

Transferability and Integration

From an agricultural perspective, indicators drawn from the literature, while appropriate to the region, need to be adapted to capture the local circumstances and conditions. Selected measures relate to the response or impacts on locally grown crops, associated farmland management practices and rural infrastructure such as roads, buildings or irrigation systems. Indicators were defined to enable the tracking of changes and trends in elements of importance relative to long-term trends (averages) for the area, which allows for fluctuations in observed trends to be considered (for example, year-to-year changes in insurance payouts).

Even though our focus was on agriculture, we were able to expand the set of indicators to rural communities and infrastructure. A large proportion of the resilience indicators were found to be also covering other sectors beyond agriculture in rural areas. This presents the need to look at the whole rural systems and capture all critical sectors, such as economic development, infrastructure, environment and natural resource management, and human health. Typically, each sector manages its suite of indicators independently, which precludes sharing of expertise and resources, and also limits the scope of risk to the particular sector. The outcomes from this work show that many of the important indicators can be used by other sectors, and that, in the absence of a strong collaborative effort (and a goal) to bring together different agencies, system-based work is difficult to achieve. Focusing our planning efforts on improving resilience offers a vehicle to bring together different sectors so that diverse information needs are met, thereby optimizing government's traditionally sectoral-focused methods (silos).

Finally, the indicators in this study where developed in the context of Ontario, but are highly relevant to other agricultural regions in Canada. They focus on major types of changes in natural and socioeconomic aspects of the area, such as changes in growing season, share for vulnerable population and share of roads in vulnerable areas, instead of specific climate change and sectorial indicators that can be highly regionally specific.

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