A review of concepts and criteria for assessing agroecosystem health including a preliminary case study of southern Ontario

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Abstract

The model of agroecosystem health has been advocated as an appealing guideline for agricultural research. Yet, some ambiguity remains in how the concept can be defined and how the general criteria for assessing the health of an agroecosystem at a particular scale can be selected. This paper reviews the literature from various disciplines pertinent to the concept of agroecosystem health. It focuses on assessing the applicability of assorted concepts, norms, and criteria to agroecosystem health assessment, and develops a general definition of agroecosystem health. A classification scheme is proposed which scattered while potentially useful concepts in the literature are discussed, using southern Ontario as a case study to further illustrate the usefulness of the conceptual framework in studying agroecosystem health. Agroecosystem health can be characterized from four different perspectives that are related to agroecosystem structure, function, organization, and dynamics. Given the complexity of agroecosystems, the health of the systems at different scales cannot be fully captured from one perspective only. Criteria, such as resource availability, diversity, and accessibility, are some of the existing concepts capable of depicting the structural state of agroecosystem health. Concepts including productivity, efficiency, and effectiveness appear very useful for assessing the functional performance of agroecosystems. As any agroecosystem interacts actively with its external environments and changes over time, such characteristics are not necessarily captured by structural or functional criteria. Organizational criteria, such as autonomy and self-dependence, are useful to characterize the organizational nature inherent to agroecosystem health. Stability and resilience on the other hand are two appealing concepts capable of revealing the temporal dimension of agroecosystem health. Numerous empirical studies that are used to illustrate how these concepts developed in different disciplines of agricultural research can be potentially employed to facilitate the assessment of agroecosystem health. It is argued that any holistic investigation of the health of an agroecosystem needs to examine biophysical, economic, and human conditions of the system and to evaluate these conditions from perspectives pertinent to system structure, function, organization, and dynamics. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Agroecosystem; Agroecosystem health; Agroecosystem health assessment; Agroecosystem health criteria; Agricultural land use

1. Introduction

Concerns over the long-term sustainable development of agriculture, range from the maintenance of a supportive biophysical resource base, the economic viability of production, and the continuation of a sufficient supply of agricultural products, to the social vitality of agriculture-based rural communities (Douglas, 1984; Brklacich et al., 1991; Science Council of Canada, 1992; Brown, 1995). These concerns have stimulated considerable interest in the relationships that shape the development of agroecosystems, and
consequently generated various concepts, theories, and models for analysing the issues relating to agriculture. One of the models proposed recently is the ‘health’ of agroecosystems. Analysts attempt to use the health model to describe and evaluate the state of agroecosystem conditions (Waltner-Toews et al., 1993). While there is considerable ambiguity as to how the health of an agroecosystem could be defined and further analyzed, the model of agroecosystem health may provide new insight into how agroecosystem conditions can be perceived.

By reviewing the literature, this paper examines the ways in which the health of agroecosystems may be characterized. A discussion of various concepts relevant to agroecosystems research is presented followed by a definition of agroecosystem health with reference to the structural and functional performance of an agroecosystem. A classification scheme is developed as a framework to review and evaluate criteria and indicators appearing in the literature for their utility in assessing different aspects of agroecosystem health. Based upon agricultural census information, a case of southern Ontario is given to illustrate the applicability of the developed framework to agroecosystem health research.

2. Agroecosystems: dimensions and scales

The notion of the agroecosystem represents a way of perceiving agriculture, particularly its environment–production relationships, in systems terms. This perspective has evolved from general systems analysis in engineering (Tivy and O’Hare, 1981). The concept of a system has been defined in various ways depending on the objective and interest of the individual researcher (Conway, 1985). An agroecosystem might be defined as a functional unit, producing agricultural products and providing rural services, which includes a set of agriculturally related elements and interactions among those elements. For instance, agricultural land, labour, capital, and management can be identified as the input elements for an agroecosystem at the farm level (Illbery, 1985). These elements inter-link with one another and interact with external attributes. The internal and external interactions determine various functions of an agroecosystem.

To simplify the complex relationships in agroecosystems, one fundamental approach is to divide the system into some broad dimensions or components (Table 1 gives three examples of this approach). For example, Smit and Smithers (1994a) propose a model for describing the relationship among agroecosystem components. The model identifies three essential dimensions constituting an agroecosystem: environmental, economic, and human dimensions. These dimensions exist in agroecosystems at different scales. The fundamental idea of such an approach is to analyze the complexity of an agroecosystem by characterizing each component part separately and exploring the relationship among those parts. The understanding of an agroecosystem as a whole depends largely on how the inherent interactions among these dimensions are recognized and generalized.

One essential element of a systems approach to agriculture is the effect of spatial scale. According to the hierarchical theory of systems analysis (Kast and Rosenzweig, 1972; King, 1993), agroecosystems can be defined at different spatial scales, ranging from field plots to the entire globe (Conway, 1985). Fig. 1 is a schematic diagram that illustrates how

<table>
<thead>
<tr>
<th>Agroecosystem constituents</th>
<th>Agroecosystem and subsystems</th>
<th>Agroecosystem dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial organization</td>
<td>Human subsystem</td>
<td>Environmental dimension (e.g. soil)</td>
</tr>
<tr>
<td>Crop-livestock production</td>
<td>Environmental subsystem</td>
<td>Economic dimension (e.g. market)</td>
</tr>
<tr>
<td>Resource management system</td>
<td>Generic subsystem$^d$</td>
<td>Human dimension (e.g. rural community)</td>
</tr>
<tr>
<td>Labour management system</td>
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</tbody>
</table>

$^a$ From Olmstead (1970).
$^b$ From Turner and Brush (1987).
$^c$ From Smit and Smithers (1994a,b).
$^d$ This refers to genotypes and phenotypes of cultivars and animals, and population dynamics that affect crop and animal evolution.
agroecosystems at macro-, meso-, and micro-scales are interrelated and nested in a systems hierarchy. An agroecosystem at a lower level (e.g. a farm level agroecosystem) is a subsystem of an agroecosystem at a higher level (e.g. a regional agroecosystem). Across various scales, agroecosystems may be composed of different components and exhibit different interactions among the components. A full grasp of the functional and structural characteristics of an agroecosystem may depend partly on how findings in different studies are integrated across scales.

3. Agroecosystem health

The concept of health is often loosely referred to in medicine as a body free of disease (Rapport, 1989; Costanza, 1992). This type of definition of health is of little utility to agroecosystem research, especially when research focuses on economic or human aspects of the system. This is due to the fact that our knowledge of agroecosystem ‘diseases’ is limited, and also because a ’negatively’ defined concept of agroecosystem health provides few directives for maintaining the health of the system. The World Health Organization describes health as one’s ability to satisfy needs and realize aspirations, as well as to cope with stresses (WHO, 1992). This description of health focuses on the social and personal resources and supportive environments, as well as physical capacity (Waltner-Toews et al., 1993). It clarifies that defining the health of a system also requires a consideration of the societal context with which people’s needs and wants are associated. The WHO (1992) description stresses that health is directly related to one’s ability or capability to function and adapt to changes in the environment.
Table 2
Characteristic response of ecosystems to stress

<table>
<thead>
<tr>
<th></th>
<th>Nutrient pool</th>
<th>Primary productivity</th>
<th>Species diversity</th>
<th>Size distribution</th>
<th>System retrogression</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Harvesting of renewable resources</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquatic</td>
<td>*</td>
<td>*</td>
<td>−</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>+</td>
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<tr>
<td><strong>Pollutant discharges</strong></td>
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<tr>
<td>Aquatic</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>+</td>
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<tr>
<td><strong>Physical restructuring</strong></td>
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</tr>
<tr>
<td>Aquatic</td>
<td>*</td>
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<tr>
<td>Terrestrial</td>
<td>−</td>
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<td>+</td>
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<tr>
<td><strong>Introduction of exotics</strong></td>
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<tr>
<td>Aquatic</td>
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</tr>
<tr>
<td>Terrestrial</td>
<td>*</td>
<td>*</td>
<td>−</td>
<td>−</td>
<td>+</td>
</tr>
</tbody>
</table>

*The signs, + and −, indicate directions of change compared with normal functioning of relatively unstressed system. The asterisk denotes the characteristic response not sufficiently determined (Rapport et al., 1985).

One approach to define agroecosystem health stems from ecosystem health research. Many have attempted to capture the essence of what constitutes the health of ecosystems. Analysts in the field of stress ecology define the concept of ecosystem health from the ‘indicative signs’ of stressed ecosystems (Odum, 1985; Rapport et al., 1985; Schaeffer et al., 1988). For example, Rapport (1995) identified a list of indicators for assessing and evaluating ecosystem under stress (Table 2). Harvesting of renewable resources, for instance, is considered as a stress to any terrestrial ecosystem. Such activity may cause the ecosystem to respond as indicated by a decrease in the nutrient pool, primary productivity, species diversity, and size of distribution, and an increase in system retrogression. Others interpret the concept from the standpoint of ecosystem organization and changes in relation to stresses. For example, Costanza (1992) states that an ecological system is healthy and free from ‘distress syndrome’ if it is stable and sustainable, i.e. if it is active and maintains its organization and autonomy over time and is resilient to stress.

At times, ecological concepts have been directly employed to define the meaning of agroecosystem health. However, there are differences between ecosystems, mostly unmanaged, and agroecosystems, which are directly managed by humans. Gallopin (1995, p. 130) states ‘agroecosystems are particular cases of socio-economic systems, or systems composed of at least a human subsystem and an ecological (or biological) subsystem’. The recognition of agroecosystem distinctiveness has meant that analysts should be careful in defining agroecosystem health with ecological concepts, and indeed should interpret the concept within a broad perspective relative to the biophysical, economic, and human dimensions inherent to the system. Despite efforts in establishing a theoretical base for agroecosystem health assessment, the actual meaning of agroecosystem health is yet to be clarified.

4. Defining agroecosystem health

At a regional level and higher, agroecosystems are designed and managed primarily for providing food, fibre, and other agricultural products for human uses (Waltner-Toews, 1994; Gallopin, 1995). They also provide a variety of services needed by society, such as an agricultural landscape and biodiversity. To provide such end-products and services, agroecosystem components are structured in such a way that various functions and processes can be performed. Hence, both functional and structural characteristics represent
the elements of agroecosystem health at a regional level.

4.1. Agroecosystem structure

The structure of an agroecosystem is referred to as the composition and distribution of the system’s components. The focus on structural characterization has been related to the biophysical resource type and composition, the social and economic pattern and distribution, and the biophysical and human landscape form (Hoffman, 1976; Chidumayo, 1989; Burel and Baudry, 1995). The structural composition and distribution of agroecosystem components vary among different types of agroecosystems at different scales (Smit and Smithers, 1994a). Agroecosystem structure also changes over time due to the influence of various factors both within and beyond an agroecosystem (Ilbery, 1991; Troughton, 1991).

The significance of agroecosystem structure is two-fold. First, the existence and distribution of structural components provides a fundamental basis upon which an agroecosystem can function at all. In crop production systems, for instance, soil is one basic resource component that retains moisture and provides mineral substances so that the plant can perform various biological processes and grow. Structural states of soil, such as organic content in soil or thickness of topsoil, are crucial factors in determining the biophysical functioning of crop production. Second, agroecosystem structure is directly tied to societal needs. For instance, a biodiversified resource structure provides an opportunity to satisfy a variety of needs for different people (Burton et al., 1993). Also, the diversified agricultural landscape structure provides different amenity values that are appreciated by different people. Therefore, the establishment of agroecosystem structural composition and morphology is significant not only in supporting various agroecosystem functions, but also in providing services to people’s needs.

4.2. Agroecosystem function

The function of agroecosystems refers to how the system operates, given a variety of components and structural forms, to generate agricultural products and services. As a multi-dimensional entity, an agroecosystem performs different functions related to biophysical transformation and cycling, economic production and social organization. With respect to the biophysical dimension, an agroecosystem functions largely in the same way as all ecosystems. It is suggested that there are two basic types of links or flows between component parts of all ecosystems: energy flow and biophysical cycling (Tivy and O’Hare, 1981). The primary function of biophysical components is realized through plant photosynthesis and material transfer in food chains and webs. The agroecosystem is a managed ecosystem and its biophysical processes are controlled or affected by economic and social manipulation. Economically, the primary function of a regional agroecosystem is to produce agricultural products needed by our society. The economic production is again a function of factors related to agricultural markets.

4.3. Agroecosystem health defined

On the basis of the above, both functional and structural aspects represent the essential characteristics of agroecosystems. Thus, the health of a regional agroecosystem can be defined as the system’s ability to realize its functions desired by society and to maintain its structure needed both by its functions and by society over a long time.

This definition not only explicitly recognizes the importance of functional and structural characteristics in the context of societal needs, but also considers the significance of temporal changes of these characteristics in the face of changing environments for assessing agroecosystem health. Such a consideration stems from the recognition that agroecosystems are subject to various driving forces that have led to dramatic changes in agroecosystem function and structure.

5. Classification of agroecosystem health criteria

In the literature on agroecosystem analyses, some studies consider the biophysical processes of the system, and others focus on the social and economic performance of the system. In order to facilitate the review of the literature and the identification of general criteria of agroecosystem health, a simple framework is proposed. The framework categorizes the existing criteria into four groups relating
Table 3
General criteria for assessing agroecosystem health

<table>
<thead>
<tr>
<th>Structural criteria</th>
<th>Functional criteria</th>
<th>Organizational criteria</th>
<th>Dynamics criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource Availability</td>
<td>Productivity</td>
<td>Integrity</td>
<td>Stability</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Efficiency</td>
<td>Self-organization</td>
<td>Resilience</td>
</tr>
<tr>
<td>Diversity</td>
<td>Effectiveness</td>
<td>Autonomy</td>
<td>Capacity to respond</td>
</tr>
<tr>
<td>Equitability</td>
<td></td>
<td>Self-dependence/self-reliance</td>
<td></td>
</tr>
<tr>
<td>Equity</td>
<td></td>
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</tr>
</tbody>
</table>

to agroecosystem structure, function, organization, and dynamics (Table 3). These four sets of criteria represent four different approaches to analyze the health of agroecosystems. Some distinctions can be made among these approaches although they are not mutually exclusive. The first examines the structural characteristics through which the appearance or the structural ‘health’ of agroecosystems can be described and/or evaluated. The second approach assesses the performance of an agroecosystem by characterizing its function. The third approach investigates the agroecosystem conditions relative to its relationships with external environments. The focus here is to know if the agroecosystem organization is established by self-regulation mechanisms or controlled by external attributes. The fourth approach focuses on the dynamics of agroecosystems. It attempts to assess the temporal aspect of agroecosystem health and evaluate the system’s ability to cope with any possible changes in attributes within or beyond the system. At a regional scale, these approaches have all been adopted to assess the conditions of the agroecosystem across its three components.

5.1. Structural criteria

Many concepts have been employed in assessing and evaluating the structural well-being of agroecosystems. In this paper, five commonly employed concepts are discussed and appraised as to their utility to agroecosystem health assessment. They are resource availability, resource accessibility, diversity, equitability, and equity (Table 3).

5.1.1. Resource availability

Resource availability refers to the volume of resources necessary to potentially achieve or maintain system functions. Availability describes the existence and capacity of critical system components and indicates the resource potential of agroecosystems. Agroecosystem functions are dependent upon a variety of resources. A certain amount of available resources of various kinds is necessary for the agroecosystem to function at all (Gallopin, 1995). Further, the amount of resources available to an agroecosystem partly determines its capacity to meet the possible expansion of demands for agricultural products, as well as its ability to cope with any environmental change (Wall et al., 1995). Hence, this criterion represents one characteristic of how well an agroecosystem is structured. An agroecosystem with a higher level of resource availability could be argued to be healthier than the one with a lower level of resource availability, ceteris paribus.

In assessing the expected impact of prime agricultural land conversion to non-farm uses in Ontario, Cocklin et al. (1983) indicate that the continuing loss of prime farmland may adversely affect the food production capacity, especially the capability of tender fruit production in Ontario, Canada. In light of agroecosystem health, such conclusions can be directly interpreted as a possible deterioration of the health of Ontario agroecosystem into the future.

5.1.2. Resource accessibility

Resource accessibility generally refers to the ease with which the system’s resources can be accessed and utilized. It depicts another character of agroecosystem structure: the distributive relationship between resource supply and demand. The importance of resource accessibility is two-fold. Firstly, accessibility to various resources and services largely determines how well the economic and social needs within an agroecosystem can be satisfied. Secondly,
an agroecosystem with accessibility to its resources can help maintain its functions over time. When an agroecosystem is under stress, its normal functioning fluctuates, and needs to be supported by alternative resources. Accessibility often becomes one of the major determining factors in how well the system is able to adjust to the new situation and maintain its functions. An agroecosystem with high accessibility to all its resources thus exhibits a high health level.

Many studies have demonstrated the utility of accessibility concept for assessing the conditions of an agroecosystem. In a case study on the long-term change of people's accessibility to health service in the rural Ontario, Joseph and Bantock (1984) conclude that the accessibility to general practitioner services by the dispersed rural population have greatly reduced. They argue that such changes threaten the vitality of rural community well-being, which is indicative of the decline of agroecosystem health. In a comparative study of three agroecosystems in Bangladesh, Ali (1995) indicates that the success of rice crop production largely depends the accessibility of agricultural land to water during dry season, and the agroecosystem with a higher proportion of irrigated land out-performs (or is more healthy than) those with a lower level of irrigation.

### 5.1.3. Diversity

Diversity is defined in a variety of ways (Goodman, 1975; Rice, 1992; Burton et al., 1993). In ecology, the concept of diversity stems from the analysis of the complexity in evolutionary ecology of ecosystem succession (Goodman, 1975; Tivy, 1993). It is proposed that the concept captures the degree to which an ecosystem preserves its interactive pathways among components in a food-web. Such discourse on the diversity concept forms the theoretical base of the ecosystem’s stability–diversity relation (Goodman, 1975). Despite the debate over the positive relationship between ecosystem stability and diversity (Shrader-Frechette and McCoy, 1993; Tivy, 1993), the concept of diversity is still extensively used in the literature, partly due to its capability in depicting system characteristics (Boster, 1983; Brush et al., 1988). In the agroecosystem context, diversity could be broadly defined as the number of system components and the extent to which system components vary across space.

Studies in different fields have suggested the potential applicability of the concept for agroecosystem health assessment. In ecological studies, for example, many have provided evidence that the loss of ecosystem biodiversity is indicative of potential system dysfunction (Harris, 1984; Root, 1990). In farming system research, it is indicated that farm diversification may increase the ability of the system to avoid the economic loss and uncertainty induced by price fluctuation in a market, and to satisfy the societal need for food in a changing pattern of food consumption (Anosike and Coughenour, 1990; Ilbery, 1992; Napton, 1992). Furthermore, the value of agroecosystem diversity by itself is a socially desired characteristic for several reasons. Burton et al. (1993) state that the biodiversified environment has an inherent aesthetic value which is desired and appreciated by our society. Therefore, a more diversified agroecosystem is a more healthy system than a less diversified one.

Many measures and indices of ecosystem diversity exist in the literature (Goodman, 1975; Burton et al., 1993). In ecology, two aspects are central in most diversity measures: number of species and size of population. In agroecosystem analysis, the richness of a system’s components and the spatial evenness of the components are commonly used to measure agroecosystem diversity at a hierarchy of scales (Yeates, 1968; Hoag, 1969). While examining the change of agroecosystem health, Xu (1999) employed a measure of land use diversity based on the spatial composition of different land use types. Based on this measure and remotely sensed data, substantial spatial variation were identified in the changing process of rural land use diversity, indicating that both improvement and deterioration in agroecosystem health had occurred in the County of Wellington, Ontario, over the study period.

### 5.1.4. Equitability

Equitability has been defined as how evenly the products of an agroecosystem are distributed among its human beneficiaries (Conway, 1985; Marten, 1988). Conway (1985) claims that equitability can be readily described using distribution parameters of the system’s structural components (e.g. land resource distribution among households in a village). From this definition, equitability becomes another measure of the structural distribution of agroecosys-
tem components, which is equivalent to the spatial evenness captured by the concept of diversity. In ecology, equitability is often considered as a measure of ecosystem diversity (Putnam and Wratten, 1984). In this sense, the concept of equitability does not offer any utility beyond the concept of diversity. For agroecosystem health assessment, the utility of equitability concept as a health component of agroecosystems is limited. Equitability is at most a subset or a measure of agroecosystem diversity. Diversity is a much broader notion capturing the structural characteristics of agroecosystems, and is measurable in a hierarchy of scales. Moreover, the definition of equitability is somewhat vague. Conway (1987) uses the same description of equitability for the definition of equity, which is another broad notion in the literature.

5.1.5. Equity

Equity is a normative notion that appears in the discussion of agricultural sustainability (Burkhardt, 1989; Brklacich et al., 1991). In agricultural sustainability analysis, the equity theme focuses on the protection of rights and opportunity of future generations to derive benefits from resources which are in use today (intergenerational equity), and on the fairness of the distribution of benefits from agriculture between countries, regions or social groups (intragenerational equity) (Barbier, 1987; Burkhardt, 1989; Smit and Smith, 1994). In essence, the notion of agricultural equity refers to the distributive fairness of agricultural production among people across space and over time. As a subjective norm, the concept of equity can be assessed via such criteria as accessibility to resources or resource diversity. In this sense, the concept of equity represents a very broad and general notion like the concept of health.

5.2. Functional criteria

Many concepts exist in the literature for characterizing the function of agroecosystems. Agroecosystem productivity, efficiency, and effectiveness are three concepts representing the essential characteristics of agroecosystem functions (Table 3), and their utilities for characterizing agroecosystem health are discussed here.

5.2.1. Productivity

Productivity is generally referred to as the output of product per unit of resource input (Conway, 1987). It describes the ability of a system to produce outputs. In ecology, productivity is a term often used to refer to chemical energy transformation. The total amount of chemical energy fixed by an ecosystem per unit area per unit of time is defined as the ‘gross primary productivity’ (Tivy and O’Hare, 1981). In economic analyses of agriculture, productivity is often referred to as economic returns or crop yields produced per unit of resources including land and labour (Mage et al., 1989; Nguyen and Haynes, 1993).

The utility of productivity concept is widely recognized in the literature. For example, in the ecological literature, the concept of productivity is often employed as a descriptor to depict the functional characteristics of biotic components in ecosystems (e.g. grassland ecosystem by Risser (1988); forest ecosystem by Reiners (1988)). Some ecologists further suggest that declines in primary productivity are indicative of stressed or unhealthy ecosystems (Odum, 1985).

In the context of agroecosystem research, the concept of productivity can provide a meaningful measure as to whether or not an agroecosystem is satisfying societal needs for agricultural products (Waltner-Toews, 1994; Gallopin, 1995; Okey, 1996). While agroecosystem productivity is conditioned by various factors, it does represent one feature that indicates the functional performance or the health of agroecosystems. An agroecosystem with a higher productivity can be considered as healthier than one having a lower productivity, when other conditions associated with the two systems are the same.

5.2.2. Efficiency

Efficiency is often referred to as the ratio of some defined output or product to the input or cost during the system functioning (Wiegert, 1988). The efficiency of an agroecosystem has been analyzed from both ecological and economic perspectives. In ecology, efficiency is a central concept for analyzing ecological processes of photosynthesis and energy transformation. The photosynthetic efficiency, for example, is defined as the ratio between the chemical energy fixed by the plants in photosynthesis and the amount of solar energy involved in the process (Tivy and O’Hare, 1981; Wiegert, 1988). Thus, the ratio of energy output
per hectare to energy input per hectare is a common measure of the ecological efficiency of an ecosystem.

In economics, efficiency means absence of waste, or using the resource as effectively as possible to satisfy people’s needs and desires (Samuelson and Nordhaus, 1989). The agricultural economy is considered to be producing efficiently when it cannot produce more of one product without producing less of another, or reaching the maximum desired production under given resource conditions. Hence, the essence of economic efficiency concerns minimising costs while maximising the volume of economic returns or products.

The utility of efficiency concept for assessing the functional health of an agroecosystem is obvious. A highly efficient agroecosystem can be interpreted as a more healthy system than an inefficient one.

It is clear that the concept of efficiency is closely related to the concept of productivity. Both concepts can be used directly for assessing functional health of an agroecosystem, but efficiency is not equivalent to productivity. Efficiency is always in ratio value, and can only be calculated using a system’s outputs and inputs that share a common unit. Productivity is however often calculated using outputs in one unit (e.g. mass, Mg) relative to inputs in another unit (e.g. area, ha). Furthermore, a productive agroecosystem may not necessarily be an efficient one, because it may involve in the inefficient use of resources and generate vast amounts of waste.

In a comparative analysis of agricultural systems, Bayliss-Smith (1982) provides an excellent example of how these two concepts can be used as central criteria for assessing the health of an agroecosystem. Based on energy productivity and energy efficiency as the criteria, the difference among different types of village-based agroecosystems were identified at various development stages around the world. The comparative analysis of Bayliss-Smith (1982) further indicated that modern agroecosystems may be the most productive (i.e. healthiest) ones but they also promise to be the least efficient (i.e. least healthy) (Table 4).

### 5.2.3. Effectiveness

Effectiveness is a concept recently proposed as a criterion for assessing agroecosystem health (Wall et al., 1995; Waltner-Toews and Nielson, 1995). Waltner-Toews and Nielson (1995) define effectiveness as the capability of an agroecosystem to meet the reasonable goals of the stakeholder. This concept is closely related to the concept of agroecosystem efficiency, in which the goals of the system are assumed. Wall et al. (1995) argue that effectiveness modifies or qualifies the measurement of agroecosystem efficiency by taking into account the desirability of agricultural outputs.

The concept of effectiveness is a notion central to the evaluation of public policy and resource management (Mitchell, 1989). In a general sense, it can be referred to as the adequacy of a system to meet certain requirements or needs through its processing and functioning. In economic analyses, the effectiveness is often assumed as a premise upon which economic efficiency is discussed. This is why the cost effectiveness in a defined economic production system is often a measure of the system’s economic efficiency (Samuelson and Nordhaus, 1989).

In agroecosystem health analysis, Waltner-Toews and Nielson (1995) argue that the effectiveness criterion explicitly includes the ethical and aesthetic

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### Table 4

The state of agroecosystem health: some empirical evidence

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Pre-industrial agroecosystems</th>
<th>Semi-industrial agroecosystems</th>
<th>Industrial agroecosystems</th>
<th>Levels of agroecosystem health</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity(^a)</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Less to more healthy</td>
</tr>
<tr>
<td>Efficiency(^b)</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>More to less healthy</td>
</tr>
<tr>
<td>Self-dependence(^c)</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>More to less healthy</td>
</tr>
<tr>
<td>Stability(^d)</td>
<td>High</td>
<td>Low</td>
<td>–</td>
<td>More to less healthy</td>
</tr>
</tbody>
</table>

\(^a\) Measured by energy output per hectare.

\(^b\) Measured by energy ratio.

\(^c\) Measured by fossil fuel input per hectare.

\(^d\) Qualitatively measured by considering impacts of the socio-economic and biophysical environments (Bayliss-Smith, 1982).
dimensions of human goals and suggest the use of an ‘overlapping consensus’ approach to measure the goals of decision makers in different levels for agroecosystem effectiveness assessment. While this approach seems appealing, they acknowledge that the analysis can become a complex socio-political task.

In their comparative analysis of farmland preservation programmes in North America, Furuseth and Pierce (1982) demonstrate potential utility of the concept of effectiveness as a criterion for assessing the health of agroecosystems. With respect to the goal of retarding the conversion of prime agricultural land in the majority of farmland protection programmes, they conclude that the comprehensive mandatory programme, adopted in Oregon, proved to be more effective than other programmes adopted elsewhere, since evidence showed the reduced rate of farmland loss after implementing the programme.

5.3. Organizational criteria

Biophysical and human attributes beyond an agroecosystem’s boundary have been recognized as driving forces of the system (Smit et al., 1998). These external factors and interactions among them provide a broader environment within which an agroecosystem operates its functions and maintains its structure. They also cause changes in agroecosystem function and structure. One approach to the health of agroecosystems is to assess how decisively those external factors/inputs have influenced the function and structure of an agroecosystem. Or alternatively, the approach is to determine if the self-regulation mechanisms of an agroecosystem dominate the realization of agroecosystem functions and the maintenance of system structure. In essence, the approach is to identify the organizational criteria to assess or evaluate the health of an agroecosystem. Many concepts related to this approach exist in the literature (Table 3). However, for some concepts such as integrity and self-organization, although they are commonly employed, their meanings still need to be clarified and their applicability to agroecosystem health research remains unjustified.

5.3.1. Integrity

Integrity is often considered as a concept that captures the characteristics of system organization (Kay and Schneider, 1991; Waltner-Toews and Nielson, 1995). While this concept is widely used, particularly in ecosystem research, there is no commonly accepted definition of integrity. Some define integrity as the ability of a system to maintain its organization (Kay and Schneider, 1991). Others consider that a system exhibits integrity if it sustains an organizing, self-correcting capability to recover toward an end-state that is normal and ‘good’ for that system (Regier, 1993). More generally, Waltner-Toews and Nielson (1995) claim that a system has integrity when it maintains its natural, human and economic capital. In essence, system integrity means the wholeness in system functioning. Some analysts have thereby argued that ecosystem health is synonymous with, even a dimension of, ecosystem integrity (Kay, 1990; Karr, 1993; Allen et al., 1994). Many researchers are aware that assessing ecosystem integrity requires one to dissect an ecosystem by characterizing its function and structure (Allen et al., 1994). This is the task that agroecosystem health analysts attempt to undertake (Waltner-Toews et al., 1993). In this sense, agroecosystem integrity should be considered as an equivalent concept to agroecosystem health rather than an analytical criterion of it.

5.3.2. Self-organization

Self-organization is loosely referred to as the degree to which a system maintains its organization (Kay and Schneider, 1991; Waltner-Toews and Nielson, 1995). The concept of self-organization originated from analyses of physical and chemical systems. The attempt is to understand certain spontaneous behavior when the system is unstable or far-from-equilibrium. The self-organization theory, developed by Prigogine (1976), provides a framework to describe and explain the organizational behaviors of complex systems with a dissipative structure (i.e. the maintenance of system structure is achieved through its continuous dissipation of energy). The self-organising behavior occurs in open, far-from-equilibrium systems involving non-linear, auto-catalytic processes, and large flows of energy or matter from outside the system that are dissipated in maintaining its structure (Grzybowski and Slocombe, 1988). While the applications of self-organization theories to the large scale ecological and socio-economic systems are growing in the literature, some fundamental questions as to
the applicability of such concepts to non-physical systems remain unanswered. For example, is the system energy analysis an appropriate way of studying ecological and socio-economic organizations where human behavior is involved?

Ecologically, the significance of the self-organization concept is tied to recognition of the chaotic nature of dynamic ecosystems and the role of self-regulation mechanisms in balancing the relationship between the system and environmental attributes. In agroecosystem health analyses, the concept of self-organization is often considered as a measure or subset attribute of a system’s integrity (Kay and Schneider, 1991; Wall et al., 1995; Waltner-Toews and Nielson, 1995). Kay and Schneider (1991, p. 13) state explicitly that ‘(a system’s) integrity has to do with its ability to maintain its organization and to continue its process of self-organization. . . . If a system is unable to maintain its organization then it has lost its integrity’. The utility of the self-organization concept may lie in some qualitative description of ‘wellness’ of agroecosystem organization. However, there is no practical measure of the concept. Furthermore, few, if any, have provided empirical examples that demonstrate the applicability of the concept in the context of agroecosystem research. The discussion of self-organization concept largely remains at the conceptual level.

5.3.3. Autonomy

Autonomy is another concept that describes a system’s organizational identity. Autonomy means, literally, self-law, or self-government, or self-regulation (Varela, 1979). In ecosystem and agroecosystem analysis, autonomy and self-organization are essentially interchangeable terms. While the concept of self-organization is formalized in physics and chemistry, the concept of autonomy is popularly used in information and life science as well as in socio-political studies. In cognitive information research, autonomy is referred to as the generation, internal regulation, and assertion of a system’s own identity (Varela, 1979). In the field of social impact analysis, autonomy of the community is often referred to as the extent to which it (the community subsystem) is dependent on, or independent of, extra-community units in the performance of its functions (Warrent, 1978; Bowles, 1981). In agroecosystem research, autonomy is often referred to as the degree of the system’s integration, and is considered as an essential property for assessing the performance of an agroecosystem (Marten, 1988).

While cross-disciplinary usage of the autonomy concept remains vague, the essential meaning of autonomy is that a system can absorb the external disturbance by self-reorganizing its structural and functional units and continue to function by self-regulating the flows of energy, information, and materials. Leckie (1989) in a case study on farm community change in Brooke Township, Ontario, demonstrated the potential utility of autonomy for analysing agroecosystem health. Using formal participation and informal interaction as measures, it was shown that this particular rural community has remained socially quite vibrant (coherent) despite tremendous changes, triggered by the rapid industrialization of agriculture, to individual farms and to the earlier social fabric of the countryside (Leckie, 1989). Although the concept of autonomy is not directly employed in the above case, the theoretical and methodological approach in the Leckie (1989) study shares much the same line of thought as with agroecosystem autonomy assessment.

5.3.4. Self-dependence/self-reliance

Self-dependence and self-reliance are the interchangeable concepts that describe a system’s organizational relationship with external environments (Gallopin, 1995). The concept of self-dependence refers to the degree to which system-generated inputs contribute to the accomplishment of system function and the maintenance of system structure. It stresses that to be self-dependent a system should rely on its own resources and efforts. Generally speaking, a system with a high degree of self-dependence means that the functioning and structuring of the system is not determined by external attributes (Gallopin, 1995).

For assessing agroecosystem health, the utility of self-dependence is multi-faceted. Many have argued that the development of agriculture should not excessively depend on human-generated subsidies or damage adjacent ecosystems (Altieri, 1989, 1992; Giampietro et al., 1992). Various observations indicate that current agricultural practices depend on massive uses of fossil fuel energy and human capital (King, 1990; Altieri, 1992; Dick, 1992). It is suggested that such biological dependence on non-ecologically based technology may reduce the capability of the
system to sustain its productivity over time, cause the contamination of adjacent environments, and increase the scarcity of non-renewable resources (Brady, 1990; Altieri, 1992). The significance of self-generated biophysical inputs for agroecosystem development is well recognized by policy makers at different levels (Brady, 1990), and has led to the development and adoption of low-input and conservative farming practices in many regions (NRC, 1989). Self-dependence also represents the desirable economic state of an agroecosystem. For example, excessive economic dependence of agroecosystems upon external financial subsidies potentially threatens the economic viability of the systems when rapid changes occur in the external financial conditions.

In studying the relationship between agricultural development and government policies, Pierce (1992, 1993) found that the economic functions of Canadian agroecosystems had been maintained through a variety of financial programs funded by governments over the last 30 years. For example, the costs of income transfers to farmers in 1986 were CAN$3.4 billion (Pierce, 1992), and grain and oilseed production alone in Canada consumed up to 50% of federal expenditures on agriculture in the early 1980s (Pierce, 1993). It was concluded that the level of economic self-dependence and therefore the health of agroecosystems had steadily decreased since the 1960s. Bayliss-Smith (1982) indicated that the transformation from traditional to industrialized agroecosystems was associated with a decline in the self-dependence of the systems (Table 4). From the organizational perspective, such decline means that the modern agroecosystems are less healthy than the pre-industrial ones for they are incapable of generating and providing sufficient inputs to support the desired productivity.

5.4. Dynamics criteria

When attempts are made to characterize agroecosystem health from a temporal point of view, the system dynamics themselves may provide some indication of the state of agroecosystem health. Such a temporal dimension of agroecosystem health is not necessarily captured by the criteria mentioned earlier. One approach is to directly employ concepts representing the system dynamics as health criteria. Agroecosystem stability, resilience, and capacity to respond are among those considered as the system’s dynamic properties (Table 3).

5.4.1. Stability

Stability is one commonly used concept for assessing the dynamics of agroecosystems, and ecosystems in general. The concept of stability originated from ecosystem analysis, where an ecological system is traditionally described in terms of an equilibrium state (Okey, 1996). The definition of ecological stability has been vague (Hills, 1987). Analysts in ecosystem dynamics research even challenge the existence of a single steady-state of an ecosystem and argue that ecosystems encompass both multiple states of equilibria and chaos (Holling, 1986; Schneider and Kay, 1993). However, Holling (1986) definition, i.e. ‘the propensity of a system to attain or retain an equilibrium condition of steady state’, still represents the common ground for defining ecological stability. Discussions on ecosystem stability are also related to the disturbances from the environment. As Holling (1986, p. 296) claims, ‘systems of high stability resist any departure from that (equilibrium) condition and, if perturbed, return rapidly to it with the least fluctuation.’ Hence, analysing the stress–response relationships in ecosystems can enhance an understanding of the characteristics of ecosystem stability.

Agroecosystems are different from natural ecosystems, and are composed of socio-economic dimensions. The stable development of agroecosystems represents a societal goal in agriculture. Agricultural stabilization has been the goal of agroecosystem management and public policy initiatives (NRC, 1989; Troughton, 1992; Pierce, 1993). Hence, from a temporal dimension, agroecosystem stability represents an essential component of agroecosystem health. Defined as production constancy relative to various stresses, the concept of agroecosystem stability describes the dynamic nature of agroecosystem health. In this context, a stable agroecosystem is healthier than an instable one.

Studies on agroecosystem stability are abundant in the literature. In studying California agriculture, Altieri (1992) provided some empirical evidence showing the instability of the agroecosystem by using a measure of changing yields of cotton crops from 1910 to 1980. Bayliss-Smith (1982) discussed the stability of different agroecosystems by examining
qualitative changes in the relationships between the systems and their external environments (Table 4). It was suggested that the modern agricultural systems have lower stability than the pre-industrial systems (Bayliss-Smith, 1982). This is largely due to the fact that the industrialized agroecosystems depend more upon external inputs and conditions. These external inputs and conditions are difficult to manage and control, and therefore may threaten the stable development of the systems (Bayliss-Smith, 1982; Altieri, 1992).

5.4.2. Resilience

Resilience refers to the ability of a system to maintain its structure and pattern of behavior in the face of disturbance (Holling, 1973, 1986). It is argued that resilience emphasizes the boundary of a stability domain and events far from equilibrium, high variability, and adaptation to change (Holling, 1986). In the agroecosystem context, resilience refers to the ability of an agroecosystem to cope with natural and socio-economic stresses (Waltner-Toews, 1994). It is also interpreted as the ability to maintain productivity in the face of stress (Gallopin, 1995).

Resilience, although recognized as an agroecosystem property, is similar to stability. While stability focuses on the constancy of the structural and functional states of an agroecosystem, resilience describes the system’s maintenance ability, or more precisely, the coping mechanisms and strategies of the system. Hence, resilience is related to how the system uses its resources to absorb the external disturbance for maintaining its functionality. According to this understanding, some have suggested the use of resilience as a key component of agroecosystem health (Rapport, 1989, 1995; Waltner-Toews, 1994). Notwithstanding the theoretical appeal of the concept, there are difficulties in implementing the notion of resilience in the practical analysis of agroecosystem health. Few researchers, if any, have proposed a practical or numerical measure of resilience. However, qualitative analyses on agroecosystem resilience still exist in the literature. For example, Leckie (1989) concludes that rural communities in Ontario have been quite resilient. Despite rapid agricultural industrialization during the past 50 years, rural community systems in the region have been able to adapt to change. Through a shift from a more traditional economic/retail focus to a more social, recreational, educational, residential emphasis, rural communities in Ontario continue to function well, and more prominently, the social core of rural communities remains strong (Leckie, 1989).

5.4.3. Capacity to respond

Capacity to respond refers to a system’s capacity to respond to various stresses. In the field of impact assessment, capacity to respond is loosely defined as a system’s coping capacity or coping range (Burton et al., 1993). In discussing the properties of agroecosystem health, Gallopin (1995) refers to ‘capacity to respond’ as the ability of the system to react to new situations. According to Gallopin (1995), the concept brings into play both the capacity to change and the tendencies towards permanence. This interpretation for capacity to respond is essentially synonymous to resilience. Statements that equate capacity to respond to resilience can also be seen in many ecological writings (Rapport, 1989, 1995; Costanza, 1992), and in agroecosystem health literature (Wall et al., 1995).

Most discussions on the concept of agroecosystem capacity to respond remain at the conceptual level. To date, few, if any, have adopted the concept in any empirical studies of agroecosystems. Such situation may continue to exist since the two concepts discussed above not only capture the essence of agroecosystem dynamics, but are also closely related to societal goals attached to agroecosystems.

6. Changing agroecosystem health: a case study

Using many case study examples published in the literature, the proceeding sections have assessed the applicability of numerous concepts to agroecosystem health assessment. The framework outlined above illustrates, at a conceptual level, how the health of an agroecosystem and its changes can be characterized from a variety of perspectives. While presenting a detailed case study based on the above framework is beyond the purpose and scope of this paper, the case study presented here helps demonstrate the real significance of the concept of agroecosystem health, and the utility of the developed conceptual framework to empirical analyses to agroecosystem health.

From a perspective of change in agricultural land use, the objective of this case study was to investigate
temporal trends and spatial patterns in the change of agroecosystem health in southern Ontario from 1971–1991. Southern Ontario is a major agricultural region in Canada (Fig. 2). It contains metropolitan areas, rural-urban fringe areas, areas of ex-urban residential development in rural districts, agricultural heartland, and some physically marginal areas. The diversity of the region provided an opportunity for the identification of different patterns and processes of change in agricultural land use. Furthermore, many concerns have been expressed over the long-term sustainability of the southern Ontario agroecosystem (Brklacich et al., 1991; MacDonald and Bretz, 1995). Healthy agroecosystem development could contribute to the provincial economy and rural community stability.

To facilitate the empirical analysis, data on agricultural land use were derived from agricultural census of Canada, and the information on land use change was retained at the spatial unit of agricultural census subdivision (equivalent to a township). To maintain temporal consistency of spatial units in the analysis, any subdivision unit, which lacked information on any one of the required variables, was eliminated from the analysis. A total of 319 census subdivisions were included in this case study.

Three land use indicators, i.e. changes in agricultural land availability, land use productivity, and land use self-dependence, are used to capture the structural, functional, and organizational aspects of changes in agroecosystem health (see Table 5). The precise measures of the indicators are listed in column three of Table 5. The results of empirical data analysis are summarized in Table 6 to generalize the spatial patterns of change in agroecosystem health in southern Ontario between 1971 and 1991.

According to the results of analyses on changes in land resource availability during the period of 1971 and 1991, the study area experienced a noticeable decline in its improved farmland base (−9%). From this particular perspective, it is reasonable to argue that the overall level of the structural health of the agro-
Table 5
Characterizing change in agroecosystem health: land use indicators and empirical measures used in a case study of southern Ontario

<table>
<thead>
<tr>
<th>Themes</th>
<th>Indicators</th>
<th>Definition of measures</th>
<th>Scale of measurements</th>
<th>Data source and spatial unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural health</td>
<td>Change of land resource availability</td>
<td>Percent change in the area of improved farmland between 1971 and 1991</td>
<td>Ratio</td>
<td>Agricultural census of Canada at the census subdivision level</td>
</tr>
<tr>
<td>Functional health</td>
<td>Change in land use productivity</td>
<td>Absolute change in the gross value of agricultural products sold per acre of improved farmland between 1971 and 1991</td>
<td>Ratio</td>
<td>Agricultural census of Canada at the census subdivision level</td>
</tr>
<tr>
<td>Organizational health</td>
<td>Change in land use self-dependence</td>
<td>Change in the proportion of cropland area sprayed with herbicides and insecticides between 1971 and 1991</td>
<td>Ratio</td>
<td>Agricultural census of Canada at the census subdivision level</td>
</tr>
</tbody>
</table>

\(^a\) This is calculated based on 1990 comparable price.

\(^b\) An increase in the proportion of cropland area sprayed with herbicides and insecticides over time indicates a decrease of land use self-dependence.

The spatial patterns of change in the structural health of the southern Ontario agroecosystem are far from uniform. Among six conventionally defined regions (see Fig. 2), townships in eastern Ontario and the ‘golden horseshoe’ experienced the most severe decline in the structural health (<–15% in most towns), while the improved farmland base in the most productive southwestern Ontario remained constant. Central-western Ontario as a part of agricultural heartland had a slight decline in its improved farmland (Table 6). In the rest of southern Ontario, the decline of improved farmland was moderate (–5 to –15%).

The spatial pattern of change in functional health was different from the structural changes. Using change in land use productivity over improved farmland as an indicator, the functional health of the southern Ontario agroecosystem had improved greatly (CANS 347.2 per acre). Spatially, the improvement of functional health was more apparent in central-western Ontario, the ‘golden horseshoe’ around the western shore of Lake Ontario, eastern Ontario than in the rest of the study region (Table 6). The agriculturally marginal areas in the Canadian Shield experienced the least improvement in the functional health of the agroecosystem. It is noteworthy that southwestern Ontario, which possesses the best biophysical conditions for agricultural production, did not have a marked improvement in its functional health in terms of land use productivity.

Table 6
Change of regional agroecosystem health in southern Ontario, 1971–1991

<table>
<thead>
<tr>
<th>Theme</th>
<th>Agroecosystem health change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Region A</td>
</tr>
<tr>
<td>Structural health</td>
<td>Constant</td>
</tr>
<tr>
<td>Functional health</td>
<td>Slight increase</td>
</tr>
<tr>
<td>Organizational health</td>
<td>Severe decrease</td>
</tr>
</tbody>
</table>

\(^a\) For location of the regions, see Fig. 2.

\(^b\) Slight, moderate, and severe decreases denote a change in improved farmland availability of –0 to –5%, –5 to –15%, and –15% and less, respectively.

\(^c\) Slight, moderate, and great increases denote a change in land use productivity of CANS 0–280, CANS 280–400, and CANS 400 per acre and above, respectively.

\(^d\) Slight, moderate, and severe decreases denote a change in land use self-dependence according to an increase of 0–10, 10–20, and 20 and above, respectively, in the percentage of crop land area sprayed with herbicides and insecticides.
Changes in land use self-dependence are indicative of changes in an agroecosystem’s ability to maintain its structure and function. Increasing use of pesticides, particularly insecticides and fungicides (in this case, decreasing land use self-dependence) not only brings about more detrimental environmental effects and presents greater risks to human health, but it also wipes out more certain beneficial species, which often lead to the emergence of their prey as even more serious pest problem of crop production (NRC, 1989). Investigation into the changes of land use self-dependence showed that the maintenance of agroecosystem function and structure in the study region had become more and more dependent upon external inputs, i.e. pesticides. Overall, the level of the organizational health of the agroecosystem had declined during the period from 1971 to 1991, as indicated by a 16.7% increase in the proportion of crop land area sprayed with toxic chemicals. Spatially, the most severe decline of organizational health was observed in southwestern Ontario (Table 6), as most townships in this region experienced a greater increase in the use of pesticides to maintain agricultural production. In other parts of productive areas, including townships in central-western Ontario, the ‘golden horseshoe’ area, and eastern Ontario, a moderate decline of organizational health occurred during the period 1971–1991. The level of organizational health declined only slightly in less productive regions of central Ontario and at the edge of the Canadian Shield (Table 6).

7. Conclusions

Any new ideas and thoughts in agricultural research are deeply embedded in the experience and lessons generated in the established scholarship and this is no exception for the emerging theoretical framework of agroecosystem health. The concept of agroecosystem health is first based on the approach developed in agroecosystem analysis, in which the system is defined at different scales and composed of biophysical, economic, and human dimensions. The concept of health lies in the centre of agroecosystem health assessment. As an evaluative notion, assessing the health of any system demands a set of criteria relating to the structure, function, organization, and dynamics aspects of the system. Agroecosystem health is thus an evaluative concept intended to integrate a complex reality of different human and biophysical phenomena and processes at a variety scales (Smit et al., 1998).

Given the nature of agroecosystem health, it is not surprising that many concepts and approaches developed in different disciplines contribute to the understanding of agroecosystem health. However, the complexity of agroecosystem health cannot be fully captured from one perspective only. For any holistic investigation of agroecosystem health, which is the emerging position of the health paradigm, analysts may need to examine the conditions of agroecosystem health from many aspects of the system including structural, functional, organizational, and dynamic characteristics.

Empirical investigation of agroecosystem health can be conducted at different spatial scales. As an initial attempt, the case study presented above demonstrates how the conceptual framework described can be implemented in agroecosystem health research at a broad regional scale. The case study reveals the complexity involved in the change of agroecosystem health. The improvement of one aspect of the agroecosystem, such as increasing productivity and hence improving functional health, does not promise any enhancement in the other aspects. Such complexity is also evident in agroecosystems at a village level (e.g. Bayliss-Smith, 1982) or a regional level (e.g. Smit et al., 1998). There is a need to simultaneously investigate different aspects of agroecosystem health at different scales so that the nature of agroecosystem health can be better understood.

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