Measuring ecosystem integrity in agroecosystems and rural communities

by David Ernest Knox

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

Abstract:
I developed an ecosystem integrity index by measuring environmental indicator variables in the area surrounding and including Three Forks, Montana. I assumed that ecosystem integrity changes as a function of land use. In upland areas, highway roadsides and native shrub rangeland ranked highest and irrigated cropland and commercial sites ranked lowest in ecosystem integrity. In valley bottom areas, forested riparian range sites ranked highest and commercial and industrial land uses ranked lowest in ecosystem integrity. Average ecosystem integrity scores for land uses were transferred to a GIS format map. I combined data from aerial photos for the years 1965, 1979, 1984, and 1990 with ground surveys in 1994, 1995, and 1996 to complete a time series of land use and ecosystem integrity. Historical events were correlated with land use changes and the resultant change in the overall ecosystem integrity of the study area. The institution of the Conservation Reserve Program had the greatest effect on overall ecosystem integrity of the study area. An approach to assessing rangeland health using visually estimated indicators of soil and vegetation condition was Compared to the ecosystem integrity index. Visual estimates correlated with measured variables. Results were repeatable between samplers 16 percent of the time. Results need to be compared to a reference site for interpretation. I tested the hypothesis that net radiation measured above the plant canopy is correlated to ecosystem structure and ecosystem integrity. Net radiation and plant canopy volume were measured four dates from June 7 to September 29 1996 across eight agricultural land uses. Net radiation was not significantly correlated to plant canopy volume in any land use or significantly correlated to ecosystem integrity across land uses. There may be different results if sampling occurs over more months of the year. I tested the hypothesis that soil color value could be used to predict percent soil organic matter across different land uses within the same landform. Regression models were developed that predicted soil organic matter to within 0.5 percent 67 percent of the time in upland areas and 10 percent of the time in valley bottom areas.

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David Ernest Knox

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

I developed an ecosystem integrity index by measuring environmental indicator variables in the area surrounding and including Three Forks, Montana. I assumed that ecosystem integrity changes as a function of land use. In upland areas, highway roadsides and native shrub rangeland ranked highest and irrigated cropland and commercial sites ranked lowest in ecosystem integrity. In valley bottom areas, forested riparian range sites ranked highest and commercial and industrial land uses ranked lowest in ecosystem integrity. Average ecosystem integrity scores for land uses were transferred to a GIS format map. I combined data from aerial photos for the years 1965, 1979, 1984, and 1990 with ground surveys in 1994, 1995, and 1996 to complete a time series of land use and ecosystem integrity. Historical events were correlated with land use changes and the resultant change in the overall ecosystem integrity of the study area. The institution of the Conservation Reserve Program had the greatest effect on overall ecosystem integrity of the study area. An approach to assessing rangeland health using visually estimated indicators of soil and vegetation condition was compared to the ecosystem integrity index. Visual estimates correlated with measured variables. Results were repeatable between samplers 16 percent of the time. Results need to be compared to a reference site for interpretation. I tested the hypothesis that net radiation measured above the plant canopy is correlated to ecosystem structure and ecosystem integrity. Net radiation and plant canopy volume were measured four dates from June 7 to September 29 1996 across eight agricultural land uses. Net radiation was not significantly correlated to plant canopy volume in any land use or significantly correlated to ecosystem integrity across land uses. There may be different results if sampling occurs over more months of the year. I tested the hypothesis that soil color value could be used to predict percent soil organic matter across different land uses within the same landform. Regression models were developed that predicted soil organic matter to within 0.5 percent 67 percent of the time in upland areas and 10 percent of the time in valley bottom areas.

Chapter 1

DEVELOPING AN ECOSYSTEM INTEGRITY INDEX FOR AGROECOSYSTEMS AND RURAL COMMUNITIES

Introduction

The concept of ecosystem integrity has not been widely applied to land management in rural agroecosystems (McKenzie, et al., 1992). Developing an understanding of ecosystem integrity and ways to monitor it is a crucial component to any research program studying sustainability of agriculture. Though ecosystem monitoring has taken place for many years, (Dyksterhuis, 1949) few methods and frameworks exist for producers and land managers to easily monitor trends in health of agroecosystems (Doran and Parkin, 1994). If the trend towards lower inputs in agricultural systems is to succeed, more intensive management must replace physical inputs. Monitoring tools need to be developed to sustain and make more efficient use of resources (National Research Council, 1994; Meyer, et al., 1992).

Objectives

The objectives of this study were to: 1) Create an ecosystem integrity (EI) index for measuring and assessing the integrity of rural and agricultural ecosystems in the Northern Rocky Mountains. 2) Assign an EI index score to each different land use occurring in the study area surrounding the town of Three Forks, Montana. 3) Create maps of land use in the study area in a GIS format for the years 1965, 1979, 1984, 1990, 1994, 1995, and 1996 based on aerial photos and on ground observations. 4) Create maps of EI in the study area based on the EI assigned to each land use in the time series of land use GIS maps. 5) Interpret trends in EI over time and relate them to changes in land use.

What is Ecosystem Integrity?

There is no single definition for ecosystem integrity. The National Research Council, 1994 defined ecosystem integrity, as: "*The degree to which the integrity of the soil and the ecological processes of range land ecosystems are sustained.*" In addition, they recommend that the term 'range land health' be used to indicate the degree of integrity of the soil and ecological processes that are most important in sustaining the capacity of the range lands to satisfy values and produce commodities. Regier, (1993) described an ecosystem with integrity with the following attributes: 1. Energetic, natural ecosystem processes are strong and not severely constrained; 2. Self-organizing, in an emerging evolving way; 3. Self-defending, against invasions by exotic organisms; 4. Robust with capabilities in reserve, to survive and recover from occasional severe crises; 5. Attractive, at least to informed humans; and 6. Productive, of goods and opportunities valued by humans.

Ecosystem health has also been defined as an ecosystem that is ecologically fit, able to tolerate environmental stress, and free of pathogens that will affect its functioning and longevity (Mouat et. al. 1992). The Environmental Protection Agency published a working definition associated with the EMAP Project which states that an ecologically sustainable agroecosystem maintains or enhances its own long term productivity and biodiversity, the biodiversity of surrounding ecosystems, and the quality of air, water, and soil (Campbell et. al. 1994). Kay (1991) noted that the concept of ecosystem integrity must have an anthropocentric component that reflects those changes in the ecosystem considered acceptable to human observers. They went on to say that otherwise one is restricted to defining ecosystem integrity as the ability to absorb environmental change with out any ecosystem change. If an ecosystem maintains its organization in the face of changing environmental conditions, then it has integrity (Kay and Schneider, 1992). Biological integrity is the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having species composition and functional organization comparable to that of the natural habitat of the region (Karr and Dudley, 1981). Biological integrity is the maintenance of the community structure and function characteristic of a particular locale or deemed satisfactory to society (Woodley, 1993). A thing is "right" when it tends to preserve the integrity, stability and beauty of the biotic community. It is "wrong" when it tends to do otherwise (Leopold, 1939).

Wickium and Davies (1995) argued that the concept of ecosystem integrity is a value-laden concept and can only be based on the kind of ecosystem desired by society. They observed where no humans are present, the notion of health or integrity of an ecosystem may be meaningless. It may be said that the integrity of an ecosystem is related to the amount or type of impact society is willing to accept for that ecosystem (Regier, 1993, Kay, 1993).

Historically, high productivity dominated the societal view of what was preferred in a managed ecosystem. Monitoring has been directed accordingly (Meyer, et al., 1992). A more recent trend has been towards environmental and economic optimization as the reference point for land managers (Meyer, et al., 1992). The reference point, that society will accept for ecosystem integrity, is sustainability (Doran et al, 1996; Hoffman and Carroll, 1995; Becker and Ostrom, 1995).

Sustainability must refer to the social as well as the biophysical component of an ecosystem, especially in agroecosystems (Heck, et al, 1991, Rapport, 1992). Some land uses are more appropriate and sustainable on certain landscapes than others are. The land uses that maintain ecosystem function will be sustainable (Doran and Parkin, 1994). Continuation of use of the land is possible if ecosystem integrity is maintained. Therefore ecosystem integrity is partially a function of land use. We have arrived at a working definition of ecosystem integrity that assumes that it is a continuous dependent variable that is referenced by an area with minimal non-natural disturbance. High ecosystem integrity is the state in which an ecosystem maintains and sustains its function at all trophic levels and supports the continuous present level of human activity.

Monitoring Theory

There is a growing body of literature that examines the selection of ecosystem or integrity indicator measurements. Mouat, et al. (1992) suggested three approaches or criteria for assessing ecosystem health: identification of systematic indicators of ecosystem functional and structural integrity; measurement of ecological sustainability or resiliency; and an absence of detectable symptoms of ecosystem stress. Ecosystems have been described as dependent on four main processes: water cycling, mineral cycling, energy flow, and plant community succession (Savory, 1988). A monitoring system based on this framework would include measurements that indicate the degree of functioning of these four ecosystem processes. The National Research Council (1994) listed three criteria for identifying ecosystem integrity: soil stability and watershed function; distribution of nutrients and energy; and recovery mechanisms.

Others have attempted to reduce ecosystem integrity to simple measurements of incoming and out-going energy as an indicator of ecosystem structure necessary to process and degrade incoming solar radiation (Schneider and Kay, 1994). The Environmental Protection Agency (Cambell, et al., 1994) has emphasized EI indicators based on societal values. They identified EI assessment questions and indicators that would determine quality of air, water and soil, ecosystem productivity; and biodiversity.

The study of soil health is much more developed in terms of field parameters examined, than is the field of terrestrial ecosystem health. Various researchers have published their lists of minimum data sets for indicators of soil health, (Doran and Parkin, 1994; Larsen and Pierce, 1991; Karlen and Stott, 1994). In agroecosystems where vegetation is regularly grazed or harvested, and soil is often disturbed, soil quality measures can play a large role in determining the overall health of the ecosystem.

Selection of Indicators

No single property can be used as an index of ecosystem integrity (National Research Council, 1994, Steedman and Haider, 1993). Selection of indicators should be based on a set of factors: the land use; the ease and reliability of measurement; variation between sampling times and across sampling area; the sensitivity of the measurements to changes in management; and the skills required for use and interpretation (National Soil Survey Center, 1996, Weaver and Forcella, 1979). Ecological indicators should be sensitive to anthropogenic stress and should be predictable in unperturbed systems (Frost, et. al. 1992). Keddy, Lee, and Wisheu (1993) state that ecological indicators should be ecologically meaningful, indicate changes at the community scale, make sense when measured across different community types, respond quickly to stresses, and be easy to measure. Choice of indicators will almost always be related to regional data sources and information needs (Steedman and Haider, 1993).

Materials and Methods

Our approach was to quantify ecosystem integrity (EI) by selecting measures that represented processes and structures that were important in maintaining ecosystem function. The processes governing EI were identified as the water cycle, mineral cycle, and energy cycle (Savory, 1988, National Research Council, 1994). Structural components were based on plant community structure and presence of animal and microbial organisms. We assumed that EI was determined by the degree that the water, mineral and energy cycles and the structural components of the ecosystem were intact. We assumed that each process had a set of specific measures or variables that assessed how intact that process was in the ecosystem under any particular land use. We assumed that the degree of EI could be determined by recording a combination of variables in a cumulative score and creating an EI index (Karr, 1993, Adamus, 1992). We based our method on the preponderance of evidence approach suggested by National Research Council (1994) to characterize as much of the ecosystem as possible. The list of variables composing the EI index was edited down to the measures that were significant in determining the EI index score (Meyer, et al., 1992).

Study Area

Sampling took place during June and July of 1995 and 1996 to correspond with peak standing crop. The study area was a 67.5 km^2 area surrounding Three Forks, Montana (population approximately 1,800). We realized early on that the study area had to be stratified so that environmental variation would not confound the variation due to land use. The study area was stratified by landform into upland sites and valley bottom sites. A t-test conducted to compare the soil moisture contents of soil samples from upland plots and valley bottom plots showed a significant difference and validated the decision to stratify the sample sites. Thus, two separate EI indices were developed, one for the upland area and one for the valley bottom. Soils were silt loams from loess parent material in the upland area, and loams to sandy loams from alluvium parent material in the valley bottom. The study area receives an average of 30 cm of precipitation per year.

Sampling was conducted on a variety of land uses within the study area (Table 1). Until approximately 1970, the dominant land use was cattle grazing on the native short grass steppe. Native vegetation in the upland was dominated by blue grama (*Bouteloua gracilis)*, and sagebrush (*Artemesia tridentata)*. During the 1970's much of the upland area was converted to wheat production. In the mid 1980's the Conservation Reserve Program (CRP) went into effect. This government program paid farmers to take land out of production and plant it to perennial ground covers. CRP lands were mostly planted to crested wheatgrass (*Agropyron cristatum*) or a mixture of crested wheat grass and alfalfa (*Medicago sativa*). In 1996, some CRP land was taken out of the government program and grazed. Seeded range sites were grazed lands planted with Bosoyski Wild Rye (*Elymus giganticus*).

Table 1. Land use classes sampled in the Three Forks study area.

Land use classes sampled	**Land form**	**Number of grid units sampled**
Valley bottom dryland hay	valley bottom	1
Valley bottom commercial	valley bottom	1
Upland commercial	upland	1
Conservation Reserve Program	upland	8
Upland dryland hay	upland	2
Dryland wheat fallow	upland	2
Forested riparian	valley bottom	3
Valley bottom grazed native range	valley bottom	2
Upland highway roadside	upland	3
Industrial	valley bottom	1
Irrigated alfalfa	upland	1
Irrigated wheat	upland	2
Non-forested riparian	valley bottom	3
Residential	valley bottom	3
Seeded range	upland	4
Native shrub range	upland	5
Ungrazed valley bottom native range	valley bottom	1
Valley bottom highway roadside	valley bottom	3

One upland dryland hay field was mixed native species, *Medicago sativa* and *Agropyron cristatum* sampled after cutting in 1995 and before cutting in 1996. The other hay field was planted with a mixture of *Elymus giganticus* and *Agropyron cristatum* and sampled before cutting in 1995 and 1996. The irrigated wheat and irrigated alfalfa sites were center pivot irrigated. The wheat and fallow fields were rotated each year. The upland commercial site was the parking lot of the local flourmill. The upland highway embankment sites were revegetated roadsides dominated by *Agropyron cristatum,* along Interstate Highway 90 (constructed in 1972).

The historic use of the valley bottom sites has been cattle pasture. Forested riparian sites were cottonwood groves (*Populus tricocarpa*) along the Jefferson river. Non forested riparian sites were low lying grassland areas subject to periodic flooding dominated by *Poa pratensis, Hordeum jubatum,* and *Juncus balticus.* The highway embankment site was a revegetated roadside dominated by *Agropyron cristatum*, and smooth brome (*Bromus inermus*) along Interstate Highway 90. The ungrazed site, dominated by *Bouteloua gracilis* and *Agropyron smithii,* was the infield portion of the local airport that had been fenced off for at least the last 30 years. Boutaloua gracilis and Agropyron smithii dominated grazed valley bottom range sites. The valley bottom hay field was planted to a mix of orchard grass (*Dactyls glomerata*) and timothy (*Phleum pratense*). Residential plots were sampled in town running the main transect down the center of a street, and sampling in adjacent yards and gardens. The commercial site was main street and the industrial site was a talc processing plant. Native range sites and non forested riparian areas were distinguished by the presence of standing water.

The study area corresponded approximately to the aerial photo of Three Forks taken in 1990 (Figure 1).

The town of Three Forks is located in the lower right corner of Figure 1. The Jefferson River enters the photo in the lower left-hand corner and leaves the area in the middle of the right hand side of the photo. The Jefferson River roughly marks the dividing line where the study area was stratified between the upland and valley bottomland forms. The study area was divided into a grid of 47 by 48 sample units of approximately 6.4 acres in size. The following landmarks will help to accurately register the 47 by 48 unit sample grid on the aerial photo of Three Forks. The Mud Spring Road running diagonally across the upper right hand corner of the photo marks one boundary of the study area. The North East corner of the study area occurs at grid unit cell (21,1) at the intersection of Mud Spring Road and highway 287. Sample grid unit (47,25) on the East boundary of the study area, corresponds to the intersection of Mud Spring Road and the abandoned railroad grade.

Using aerial photos from 1965, 1979, 1984,and 1990, each grid unit was classified into a land use class (Table 1). Land use patterns were entered on a GIS map of the study area for each year that aerial photographs were available and for 1994, 1995 and 1996 when the study site was ground surveyed. Grid units selected for sampling included a representative sample of all land uses, and units that had changed land use either 0, 1, 2, 3 or 4 times in the last thirty years. The spatial distribution of sample grid units encompassed the entire the study area (Figure 1). Land owner cooperation determined accessibility to potential sampling areas.