



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

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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.

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AND RURAL COMMUNITIES**

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A thesis submitted in partial fulfillment  
of the requirements for the degree

of

Master of Science

in

Soils

**MONTANA STATE UNIVERSITY-BOZEMAN**  
Bozeman, Montana

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## APPROVAL

of a thesis submitted by

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<sup>2</sup> 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 (*Artemisia 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 Bosoyiski Wild Rye (*Elymus giganteus*).

**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 giganteus* 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 tricarpha*) 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 inermis*) 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. *Bouteloua gracilis* and *Agropyron smithii* dominated grazed valley bottom range sites. The valley bottom hay field was planted to a mix of orchard grass (*Dactylis 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.

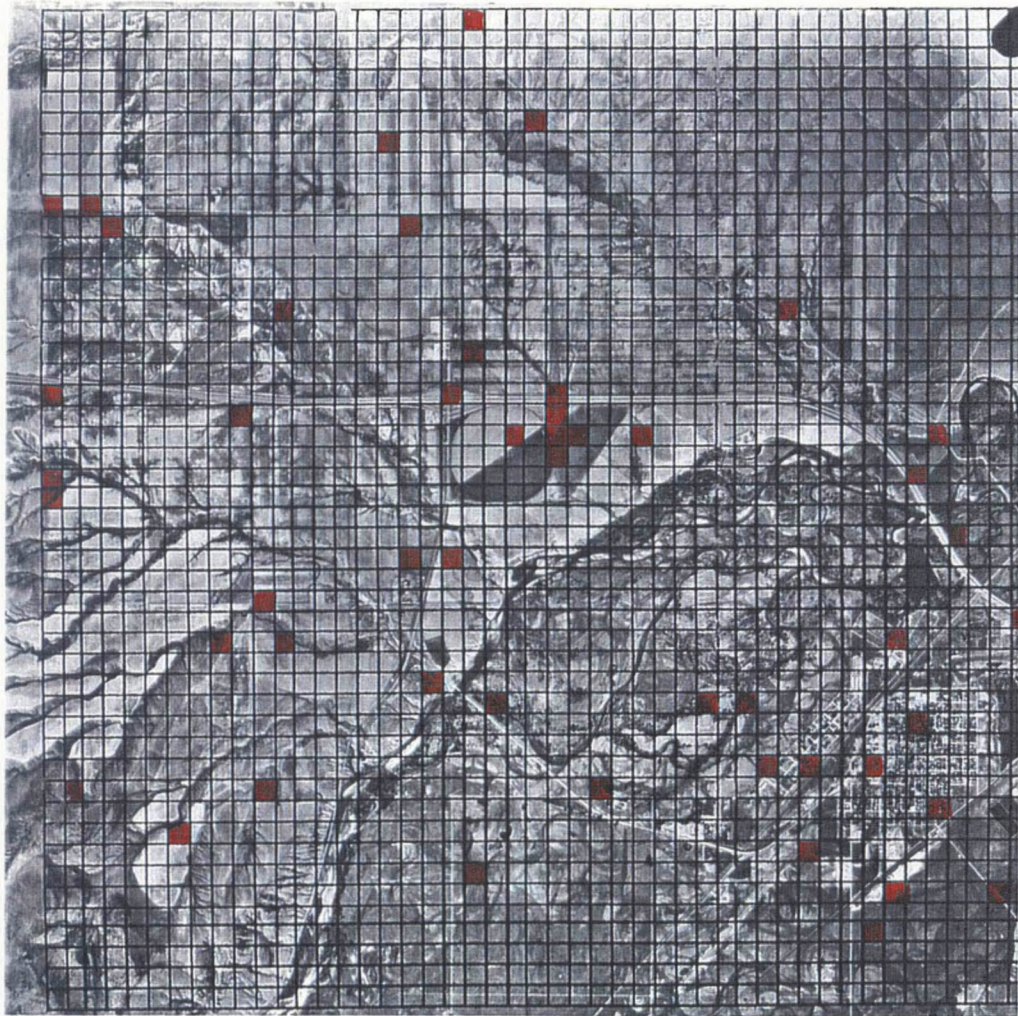


Figure 1. Aerial photograph of Three Forks with sample sites shown on grid.

### **Sampling Procedure**

In selected grid units, a 150 meter baseline was established to coincide with the predominate land use class present in the unit. Sample transects were located at 50, 100, and 150 meters perpendicular to the baseline. Six, 0.5 m<sup>2</sup> sampling frames were placed at random along each sample transect (Figure 2). A pilot study and subsequent analysis of the running totals of the variances, determined the number of frames needed to be sampled for each of the variables measured. The list of initial variables is shown in Table 2.

*Ground Cover:* The following categories were estimated in 18 sample frames per grid unit: bare soil, rock, litter, dead and downed wood, animal pellets, and plant canopy cover. Each percent cover category had the potential to reach 100%. Above ground vegetation structure was characterized as the percent of canopy cover in 3 height classes: 0-0.5 m, 0.5-2.0 m and >2.0 m (Jensen, et al., 1992).

*Plant Species Composition:* Within 18 sampling frames per grid unit, all plants were identified to species, and the percent cover by species was noted (Debinski and Brussard, 1992). For each species the life form, either annual forb, annual grass, perennial forb, perennial grass, biennial forb, perennial shrub, or tree was noted. The Shannon Weiner diversity index (Goldsmith, et al, 1986) was used to create a morphological diversity index. Whether the plant was a native, crop or introduced weed was noted to calculate percent undesirable plants. In cropped areas, both native and exotic weeds were considered undesirable; in native range sites, only exotic weeds were considered undesirable; in residential areas, only exotic weeds were considered undesirable.

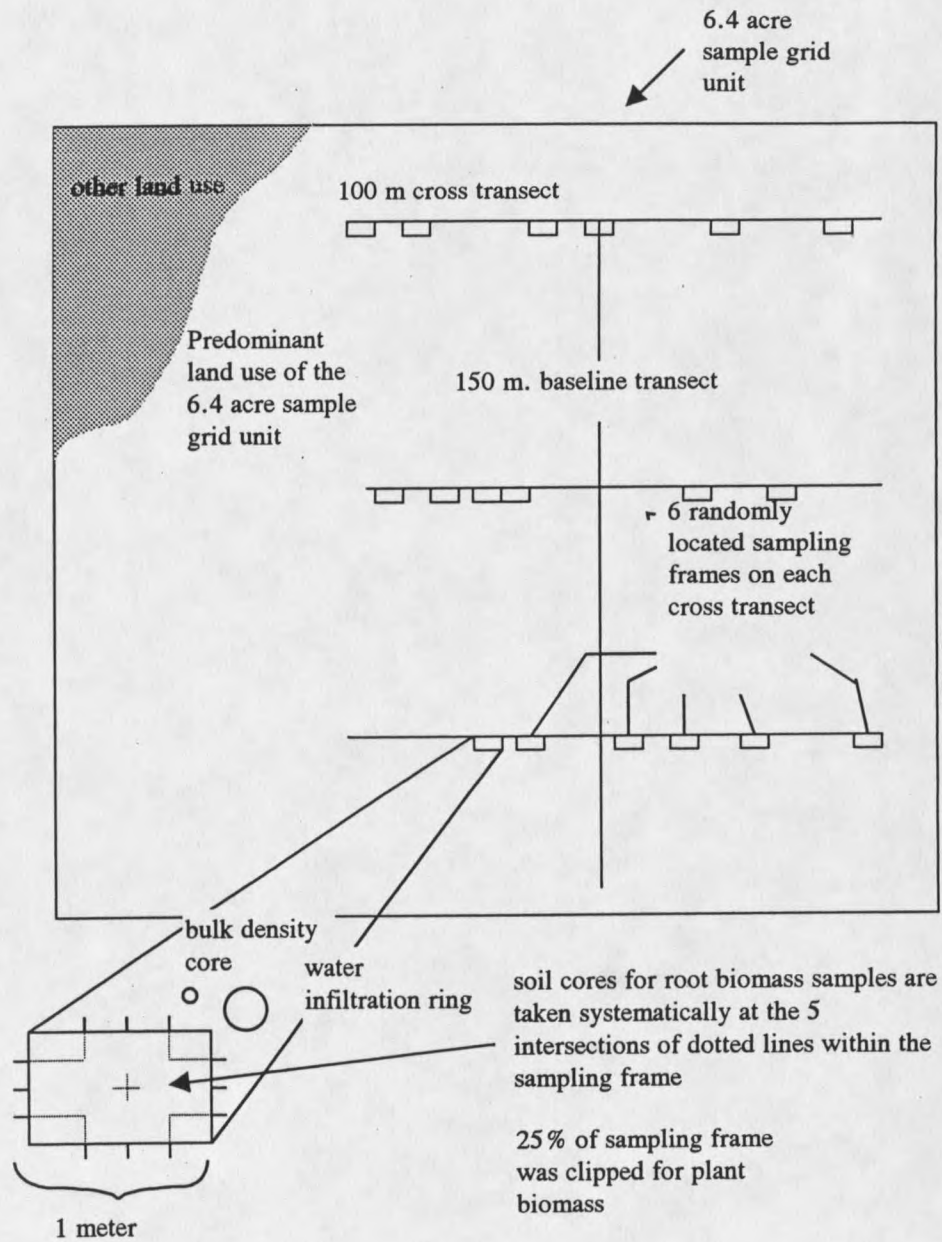


**Figure 2.** An example of the transect and sampling frame layout in a typical sample grid unit.

**Table 2.** Variables measured in the process of creating the upland actual EI index, which was used to determine the upland base reference grid unit.

| <u>Original list of variables measured for consideration in an ecosystem integrity index</u> |                               |                               |                               |
|----------------------------------------------------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|
| bare soil                                                                                    | rock or pavement cover        | litter cover                  | soil phosphorous              |
| moss cover                                                                                   | mammal taxons                 | water infiltration rate       | soil NO <sub>3</sub>          |
| standing crop biomass                                                                        | Soil nitrogen ppm             | soil bulk density             | plant morphological diversity |
| standing dead biomass                                                                        | canopy cover                  | soil respiration rate         | plant species richness        |
| litter biomass                                                                               | root biomass                  | soil organic matter           | weed cover                    |
| soil potassium                                                                               | arthropod taxons (frame)      | soil C/N                      | plant canopy diversity        |
| low canopy cover                                                                             | live/litter plant biomass     | soil NO <sub>3</sub> / N      | high canopy cover             |
| basal vegetation cover                                                                       | animal feces cover            | downed wood cover             | medium canopy cover           |
| <u>significant in 1995</u>                                                                   |                               |                               |                               |
| bare soil                                                                                    | plant species richness        | soil phosphorous              |                               |
| soil C/N                                                                                     | mammal taxons                 | root biomass                  |                               |
|                                                                                              | moss cover                    | litter cover                  |                               |
| <u>significant in 1996</u>                                                                   |                               |                               |                               |
| soil C/N                                                                                     | soil nitrogen                 | soil respiration rate         | rock or pavement cover        |
| litter cover                                                                                 | weeds                         | soil NO <sub>3</sub> / N      | mammal taxons                 |
| root biomass                                                                                 | arthropod taxons (frame)      | plant morphological diversity |                               |
| soil organic matter                                                                          | plant species richness        | live/litter plant biomass     |                               |
| <u>significant both years</u>                                                                |                               |                               |                               |
| soil nitrogen                                                                                | moss cover                    |                               |                               |
| bare soil                                                                                    | soil NO <sub>3</sub> / N      |                               |                               |
| plant species richness                                                                       | plant morphological diversity |                               |                               |
| <u>low CV over 2 years</u>                                                                   |                               |                               |                               |
| soil organic matter                                                                          | plant canopy diversity        | soil potassium                | soil NO <sub>3</sub>          |
| soil bulk density                                                                            | canopy cover                  | litter cover                  | soil NO <sub>3</sub> / N      |
| bare soil                                                                                    | plant species richness        | live/litter plant biomass     | soil phosphorous              |
| soil C/N                                                                                     | water infiltration rate       | moss cover                    | plant morphological diversity |
| <u>measures significant in at least two tests</u>                                            |                               |                               |                               |
| bare soil                                                                                    | plant morphological diversity | soil NO <sub>3</sub> / N      |                               |
| soil organic matter                                                                          | litter cover                  | soil respiration rate         |                               |
| soil C/N                                                                                     | soil phosphorous              | live/litter plant biomass     |                               |
| moss cover                                                                                   | root biomass                  | plant species richness        |                               |
| soil nitrogen                                                                                | mammal taxons                 |                               |                               |

Plant species richness was simply the number of species present in the grid unit found in the 18 sampling frames and found outside of the sampling frames during the course of completing the complete suite of measurements.

*Standing Crop/ Above Ground Biomass:* Present years plant growth (green) was clipped from six, 50 by 25 cm frames per grid unit, dried, and weighed to provide an estimate of net primary productivity in the ecosystem (Singh, et al., 1975). Standing dead plant biomass was clipped, dried and weighed. Surface litter was picked off the ground, dried, and weighed. In cropped areas we only clipped 3 frames per grid unit to minimize the impact on the crop. Since vegetation was uniform in these areas we did not expect to decrease precision with a decrease in samples. In riparian woodlands, standing crop was estimated using plant stem diameter and height and allometric relationships (Boggs, 1986). Present year production was estimated on shrubs by pulling off new leaves (Jensen, et al., 1992). The live plant to litter ratio was calculated from the average values of all frames sampled in a grid unit.

*Root Biomass:* Five, systematically located soil cores of 10 cm depth and 2 cm diameter, were taken within nine 0.5 m<sup>2</sup> sampling frames per grid unit to estimate root biomass. (Milchunas and Lauenroth, 1989, Bartos and Sims, 1974, Coffin and Lauenroth, 1991). Once per week the root core samples were washed, sieved in a # 35 soil sieve, and set to dry in a 105° drying oven for 48 hours then weighed. Results were expressed in grams of roots per m<sup>2</sup> in the top ten cm of soil

*Soil Bulk Density:* A 10 cm deep, 5 cm diameter soil core was extracted and placed in a sealed soil sample bag. Soil cores were taken adjacent to nine vegetation sample frames

at each grid unit. Each soil core was taken back to the laboratory, dried for 72 hours, and weighed. Bulk density was calculated as grams per  $\text{cm}^3$ .

*Water Infiltration rate:* A sixteen cm diameter PVC ring was pounded into the ground adjacent to nine sampling frames per grid unit, and timing the infiltration of five cm of water poured into the ring. If infiltration time exceeded sixty minutes, the time was noted as sixty-five minutes. Infiltration time exceeded 65 minutes in all of the commercial and industrial plots, and in 38 out of 439 or 8.7 percent of the samples in all the other grid units.

*Soil Temperature at 50 cm depth:* A shallow pit is dug near six sampling frames per grid unit and a soil thermometer is stuck in the shady side of the soil profile 50 cm down from the surface (Munn and Nielson, 1979).

*Soil Nutrient Analysis:* Soil samples, from the nine bulk density cores per grid unit, were pooled and analyzed for soil organic matter, total Kjeldahl nitrogen, Olsen phosphorous, potassium, and nitrate in the Montana State University Soil Analytical Lab (Weaver and Forcella; 1979 Duxbury and Nkambule 1994).

*Soil Respiration:* The open end of a one gallon tin (respirometer) can with a diameter of 15.5 cm was pounded in the ground 2 cm deep adjacent to nine sample frames per grid unit. A petri dish with 0.50 ml of 1M KOH solution was placed on a wire stand inside the tin can where the soil surface was cleared of vegetation near the sampling frame. The KOH solution was left exposed for 24 hours to measure evolved  $\text{CO}_2$ . In each grid unit control petri dishes were placed inside cans sealed at both ends. The exposed solution samples were taken back to the lab in sealed jars, titrated with 0.1M HCl (Lundegardh,

1927; Anderson, 1973; Gupta and Singh, 1976). The net evolved  $\text{CO}_2$  / $\text{m}^2$  /day was calculated according to Anderson, (1982).

*Mammal taxons present:* Pellet piles and burrows within 18 sampling frames per grid unit were identified to finest taxonomic level possible and the number of distinct taxons present in each grid unit was noted.

*Macro Arthropod taxons present:* The number of different macro arthropod taxons present inside 18 sampling frames per grid unit was noted.

### **Analysis**

The objectives of the study were to develop an EI index that adequately represented ecosystem structure and function; characterize the EI of the study area by assigning an ecosystem integrity score to each land use present in the study area; and observe the trends in EI caused by changes in land use as documented from aerial photos from 1965, 1979, 1984, 1990, and ground surveys in 1994, 1995, and 1996.

We initiated the process of developing an EI index for the upland area by identifying a subset of variables that characterized the structure and function of each sample grid unit, and also significantly contributed to an index of EI. To accomplish the reduction in variables we devised a selection process that began with a correlation analysis to determine which measurements were highly correlated with date of sampling. Correlation values significantly different from zero showed high temporal variability and therefore were rejected as candidate variables for the EI index.

Next, we used regression analysis to select variables that significantly contributed to a preliminary, unedited or "actual" EI index. To do this we *a priori* defined a desirable

condition that we subjectively identified as maximizing ecosystem function for each variable. For example we assumed that more soil organic matter was related to higher EI, and a low proportion of bare soil was associated with high EI. We scaled all the variables and calculated an average of all scaled variables to create the unedited actual EI index. We then ran a series of regression analyses on each variable versus the unedited actual EI index designating the unedited actual EI index as the dependent variable. Significant relationships ( $p \leq 0.05$ ) indicated the variables that would be used to create a refined actual EI index. The analyses were conducted on data from all grid units sampled in 1995, and then separately on all grid units sampled in 1996. This test provided a good assessment of variable performance over a wide range of land uses and over two years with different weather patterns.

In order to further assess the effectiveness of each variable and reduce the number of variables used in calculating the actual EI index, a second series of regressions were performed using only variable scores from ten grid units that were sampled in both 1995 and 1996. Raw data variable scores were re-scaled using only data from resampled grid units. This test showed which variables were significant in both years over the same land uses.

In addition, a coefficient of variation was calculated for each variable sampled in the ten grid units that were sampled in 1995 and 1996 to find the variables with the least year to year variation.

$$\frac{\sum_{plot1}^{10} |'95score - '96score| / 10}{mean\ score\ from\ '95\ \&\ '96}$$

The average of the absolute values of the differences between years for a variables' score in all ten pairs of resampled grid units was divided by the mean score of the variable across all ten pairs of grid units to give the coefficient of variation measure. Variables with a (average difference divided by the sample mean) score less than one were considered to have low year to year variation.

Variables that were significant in at least two of the four tests (significant in 1995, significant in 1996, significant in both years over the same land uses, and low coefficient of variation) were used in constructing the edited actual EI index.

To maintain our preponderance of evidence approach to measuring EI we checked that the reduced variable set included measures describing the basic components of EI, i.e. water cycling, energy cycling, mineral cycling, and structural components. The reduced set of variables was accepted if all four components were represented.

### **Referenced EI**

A second EI index was created based on referencing each sampled grid unit relative to the grid unit that scored the highest in the actual EI index (Schneider, 1992; Kay, 1993). The reference grid unit was measured in 1995 and 1996 so that referencing would not be affected by temporal variation (Weaver and Forcella, 1979). Referencing for any given variable was accomplished by taking the absolute value of the difference between the variable's score in the base reference grid unit and the variable's score in the grid unit

under consideration, and dividing this difference by the variable's score in the base reference grid unit. This calculation provided a proportional difference between the reference plot and all other grid units for each variable. The referenced values were then scaled. The scaled referenced values for each variable were averaged for each grid units to give a "referenced" EI score that served as a similarity index. In the referenced EI index, the base reference grid units always had a score of one and all other grid units had scores that reflected their proportional similarity to the reference grid unit.

The advantages of a referenced EI index are no *a priori* assumptions about optimum values for individual variable measurements; ease of interpretability; one can see if the system is close to or far away from a closest approximation of a perceived sustainable ecosystem; an ecosystem management approach is maintained when similarity to a reference system is assessed (Costanza, 1992); variables can be added to the index that have an optimum value between the maximum and minimum observed in the study region; plots from different years can be compared to each other as long as the reference grid unit is measured each year.

The same four tests used to select variables for the actual EI index were used to select variables for the referenced EI index. Therefore, variable selection was based on significant ( $p \leq 0.05$ ) regressions in 1995 and 1996 over a wide range of land uses, significance ( $p \leq 0.05$ ) in both years in resampled grid units, and low ( $cv \leq 1$ ) year to year variation based on coefficient of variation analysis.

### **Assigning EI to Upland Land Use Classes**

All plots from 1995 and 1996 were grouped by land use class. An average EI index score, using the referenced EI index, was calculated for each land use class. The EI index score for the base reference plot was not included in calculating the average for its land use class.

### **Valley Bottom EI**

No valley bottom plots were resampled in both 1995 and 1996. Assessing year to year variation and significance of a variable in both years was not possible so a separate method for determining significant variables was used. As in the upland, an EI index using actual scores was first established. When a series of regressions was run for each variable *versus* the unedited actual EI score, using EI as the dependent variable, an insufficient number of variables were selected using standard statistical criteria ( $p \leq 0.05$ ). A more lenient criteria,  $p \leq 0.12$ , was used to select variables for inclusion in the edited index. As in the upland, a referenced EI index was created, referencing all sampled grid units to the grid unit with the highest actual EI index score.

### **Assigning EI to Valley Bottom Land Uses**

All valley bottom grid units from 1995 and 1996 were grouped by land use class and an average EI index score, using the referenced EI index, was calculated for each land use class. The EI index score for the base reference grid unit was not included in calculating the average for its land use class.

Due to consideration of privacy, the maintenance of good will between property owners and the research team, and the scarcity of residences in the upland area, only residential areas in the valley bottom were measured. The new residential development that appears on the 1996 land use map (figure 19) is in the upland. EI values from the valley bottom residential grid units were used to characterize EI as a best approximation in the new subdivision even though it was located on the upland.

### **Creation of GIS Maps**

The GIS land use maps for each year were created by manually entering, for each sample grid unit, the land use codes derived from the aerial photos from 1965, 1979, 1984, 1990 or from the ground surveys from 1994, 1995, and 1996. EI index scores for each land use class were categorized and entered as a separate layer of GIS maps for each of the years. Overall EI for the study area was determined by multiplying each EI score category by the number of cells occurring in that category. The result was a time series of land use change and change in ecosystem integrity from 1965 to 1996 entered as separate layers in a GIS format.

Comparison between averaged EI values for each land use class was not conducted because the sample grid units were not sampled randomly due to access limitations and due to the existence of few repetitions of land use classes within the study region. Instead, EI scores for land use classes were treated as a continuum from low to high EI.

## **Results**

The objectives of the study were to create an EI index for measuring rural and agricultural ecosystems; assign an EI index score to each land use class in the study area; create GIS maps of land use for 1965, 1979, 1984, 1990, 1994, 1995, and 1996; create GIS maps of EI based on the land use GIS maps; interpret trends in EI over time and relate them to changes in land use.

### **The EI index**

It was hypothesized that soil temperature at a depth of 50 cm would be an integrating variable for ecosystem integrity. Lower temperatures would signify more energy processing by the ecosystem. Soil temperature at 50 cm is not subject to diurnal fluctuation (Munn and Nielson, 1979). However, it was found to fluctuate over the days of the months of June and July. Correlation analysis showed a highly significant, correlation ( $r = .707$ ,  $p < .05$ ) between soil temperature at fifty cm and date of sampling. If all the plots were sampled for soil temperature on the same date, this measure might be found to be useful for measuring EI. No other measurements were significantly correlated to date of sampling.

### **Upland EI index**

The process of selecting variables for the upland actual EI index is depicted in Table 2. Using the initial set of variables, the four tests conducted to reduce the number of variables composing the actual EI index showed: eight variables that significantly ( $p \leq 0.05$ ) predicted an EI made from the initial list of variables using 1995 data; fourteen variables

that significantly ( $p \leq 0.05$ ) predicted an EI made from the initial list of variables using 1996 data; six variables that were significant ( $p \leq 0.05$ ) in both 1995 and 1996 over a set of resampled grid units; and sixteen variables that had coefficients of variation of the between year difference in variable score  $\leq 1$ . The final list of fourteen variables in Table 2 is composed of variables that were significant in at least two out of the four tests. Using this final edited list of variables, an edited actual EI index was created. Grid unit 20 from 1995, which was also 1996 grid unit 15, a native range site, was selected as the base reference grid unit for the upland area on the basis of having the highest actual EI index score.

Table 3, shows the selection process for variables for the referenced EI index for the upland area. Using the initial set of variables to compose an unedited referenced EI index, the four tests conducted to reduce the number of variables composing the referenced EI index showed: thirteen variables that significantly ( $p \leq 0.05$ ) predicted the unedited EI using 1995 data; twelve variables that significantly ( $p \leq 0.05$ ) predicted the unedited EI using 1996 data; four variables that were significant ( $p \leq 0.05$ ) in both 1995 and 1996 over a set of resampled plots; and seventeen variables that had coefficients of variation of the between year difference in variable score  $\leq 1$ . The final list of variables in this table is composed of fourteen variables that were significant in at least two out of the four tests. Using the final edited list of variables an edited, referenced EI index was created for the upland area. The final list of variables represented the three ecosystem functions, water cycling, mineral cycling, energy cycling, and ecosystem structure. However, several

components of the ecosystem, macro arthropods, mammals, and soil microbes were not represented in the list.

**Table 3.** Variables measured in the process of creating the upland referenced EI index which was used to determine the rankings of upland grid units by EI.

**unedited list of variables**

|                  |                               |                       |                              |
|------------------|-------------------------------|-----------------------|------------------------------|
| bare soil        | soil phosphorus               | mammal taxons         | standing dead biomass        |
| rock or pavement | plant morphological diversity | arthropod taxons      | litter biomass               |
| moss cover       | plant species richness        | soil potassium        | water infiltration rate      |
| litter cover     | weeds                         | total soil nitrogen   | soil bulk density            |
| canopy cover     | plant canopy diversity        | soil organic matter   | soil respiration             |
| root biomass     | soil nitrate/ nitrogen        | soil carbon/ nitrogen | standing live/litter biomass |
|                  |                               | standing live biomass | soil nitrate                 |

**significant in 1995**

|              |                       |                        |                              |
|--------------|-----------------------|------------------------|------------------------------|
| bare soil    | root biomass          | soil phosphorus        | standing live/litter biomass |
| moss cover   | standing live biomass | plant species richness | canopy cover                 |
| litter cover | soil organic matter   | plant canopy diversity | soil carbon/ nitrogen        |
|              |                       |                        | soil nitrate                 |

**significant in 1996**

|                  |                         |                               |
|------------------|-------------------------|-------------------------------|
| bare soil        | water infiltration rate | plant species richness        |
| rock or pavement | soil bulk density       | soil nitrate/ nitrogen        |
| moss cover       | soil respiration        | soil nitrate                  |
| litter cover     | root biomass            | plant morphological diversity |

**significant in both years in resampled plots**

|                       |            |
|-----------------------|------------|
| soil nitrate          | bare soil  |
| soil nitrate/nitrogen | moss cover |

**low year to year variation**

|              |                               |                       |                        |
|--------------|-------------------------------|-----------------------|------------------------|
| bare soil    | litter biomass                | soil potassium        | soil nitrate           |
| moss cover   | water infiltration rate       | total soil nitrogen   | soil nitrate/nitrogen  |
| litter cover | soil bulk density             | soil organic matter   | plant canopy diversity |
| canopy cover | plant morphological diversity | soil carbon/ nitrogen | soil phosphorus        |
|              | plant species richness        |                       |                        |

**significant in 2 tests**

|                        |                               |                      |                       |
|------------------------|-------------------------------|----------------------|-----------------------|
| bare soil              | water infiltration rate       | soil organic matter  | soil nitrate/nitrogen |
| moss cover             | soil bulk density             | soil carbon/nitrogen | soil nitrate          |
| litter cover           | plant morphological diversity | root biomass         | canopy cover          |
| plant species richness | plant canopy diversity        |                      |                       |

To more clearly understand the process of creating the upland EI index, Figures 3 and 4 are presented showing plot rankings based on the actual EI index scores. In 1995, actual EI scores based on the reduced number of parameters showed a continuum of EI scores where a native shrub dominated rangeland grid unit had the highest score and the irrigated alfalfa grid unit had the lowest score (Figure 3).

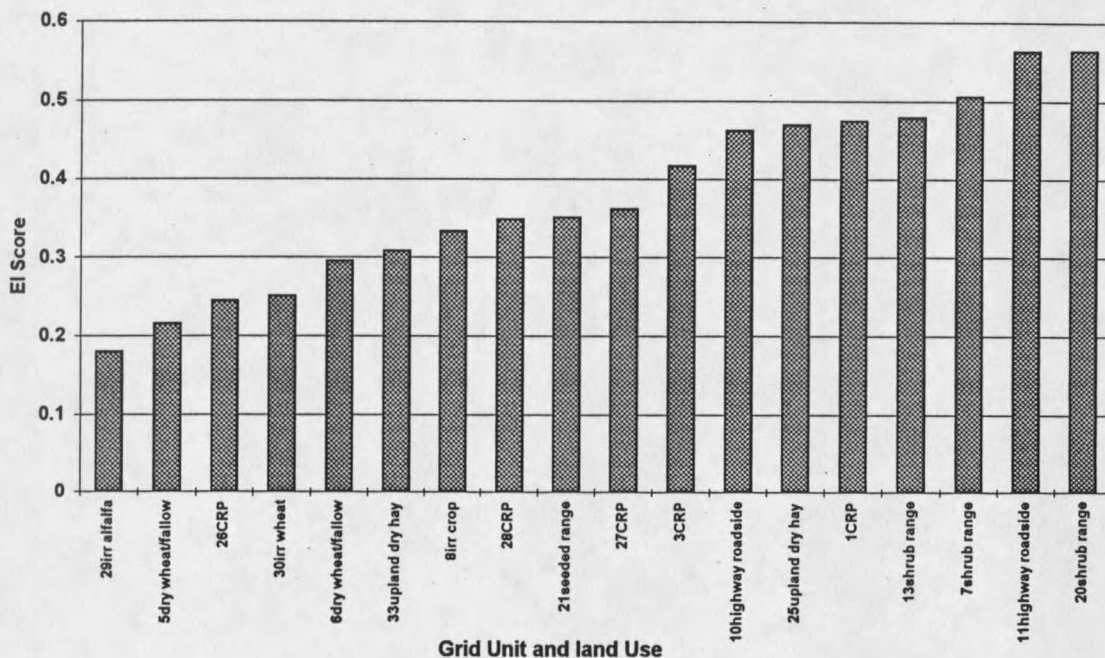


**Figure 3.** Ranking by actual EI of the 1995 upland grid units determined the upland base reference grid unit, the highest-ranking grid unit.

In 1996, actual EI scores based on the reduced number of parameters also showed a continuum of EI scores where the same native shrub dominated rangeland had the highest score and the parking lot/commercial had the lowest score (Figure 4). From the 1995 rankings, the upland base reference grid unit was chosen for the referenced approach.

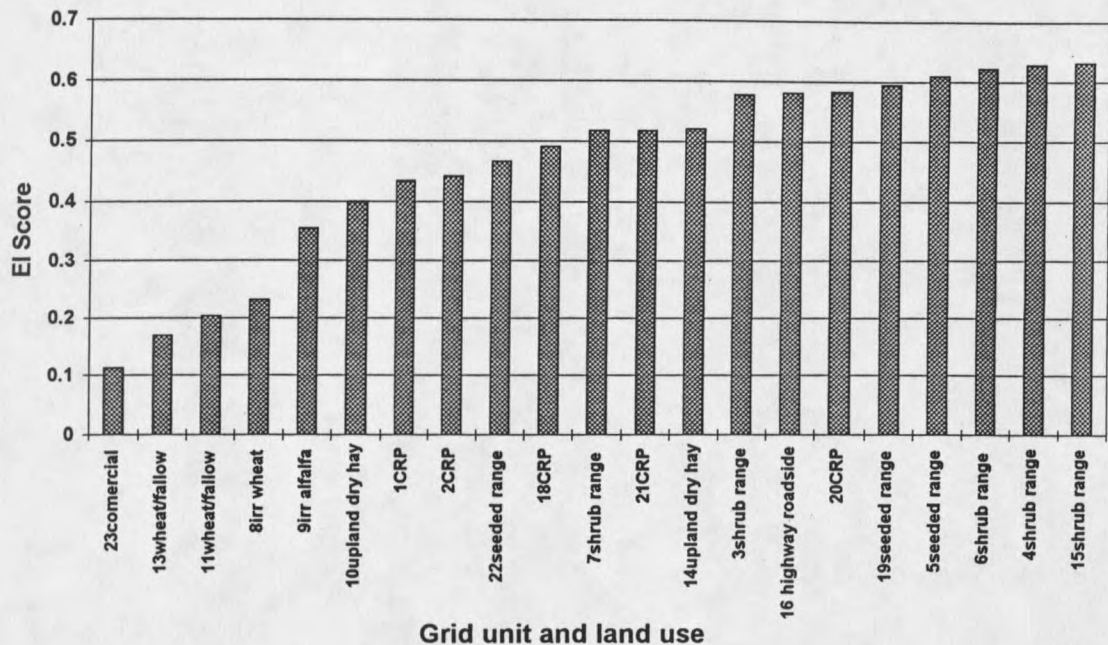


**Figure 4.** Ranking by actual EI of the 1996 upland grid units resulted in the same grid units having the highest ranking as in 1995.

### EI Values for Upland Grid Units

Figure 5 shows the combined years' upland grid units ranked by their referenced EI index score. Figure 5 shows that except for the commercial site, all except two of the uncultivated grid units ranked higher than cultivated grid units. However, a continuum of referenced EI scores was apparent in the ranking of grid units. Brackets connect grid units that were sampled in 1995 and 1996. The two dryland hay fields had low year to year variability while the shrub range plot and CRP plots had relatively high year to year variability.

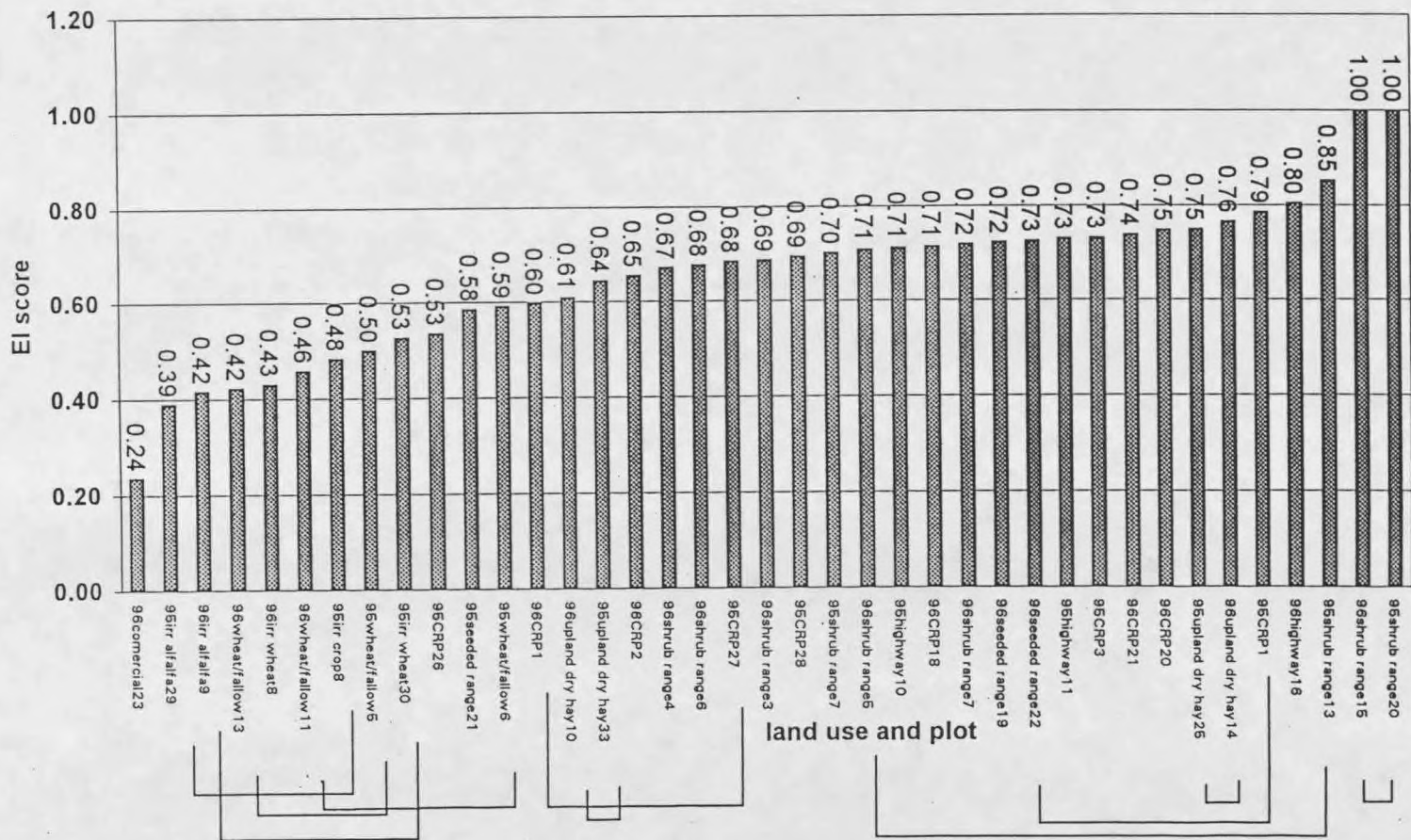


Figure 5. Ranking by referenced EI of upland plots from 1995 and 1996. Brackets indicate plots sampled in 1995 and 1996.

### EI Scores for Upland Land Use Classes

Figures 6 and 7 show the ranking of upland land use classes using referenced EI index scores from 1995 and 1996 respectively. EI index scores from grid units of the same land use were averaged together to produce an EI index score for each land use class. Figure 8, shows the ranking by referenced EI of upland land use classes using combined years data.

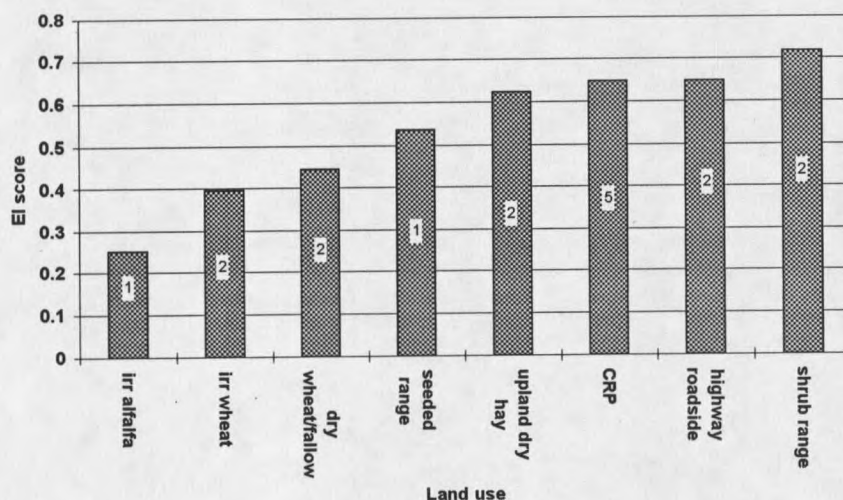


**Figure 6.** Ranking by referenced EI of upland land use classes using averaged scores from 1995 samples. The figures in the bars indicate the number of grid units sampled.

Each Figure, 6, 7, and 8 shows a different ranking of land uses. Using only 1995 EI index scores, the shrub range land use ranks highest, next is the highway roadside, and next is the CRP land use. Using 1996 EI index scores, the seeded range land use ranks first the highway roadside ranks second and the dryland hay land use third. Using EI index scores from the combined years data set, the highway roadside land use ranks first, native shrub range second, and dryland hay third. These results illustrate the variability of EI within land use classes.

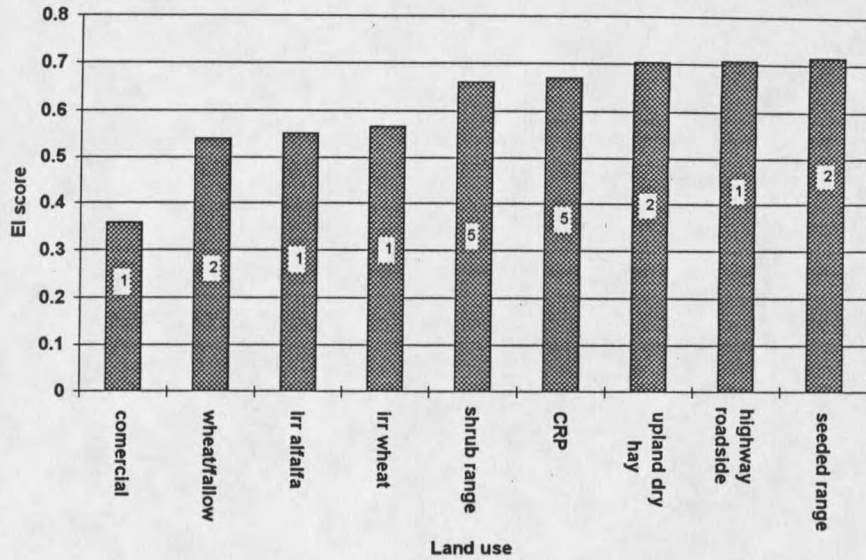


**Figure 7.** Ranking by referenced EI of upland land uses using averaged scores from 1996 samples. The figures in the bars indicate the number of grid units sampled.

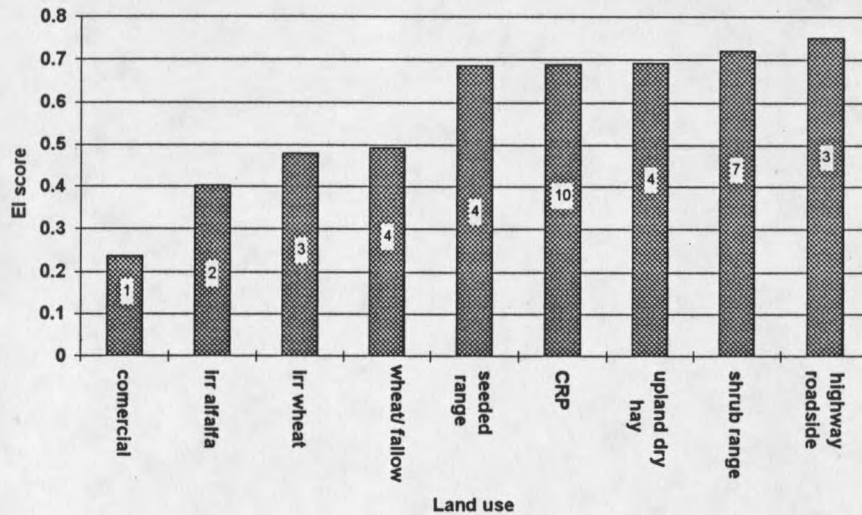


**Figure 8.** Ranking of upland land use classes using averaged scores from 1995 and 1996. The figures in the bars indicate the number of grid units sampled.

### **Valley bottom EI index**

The process of selecting variables for the valley bottom actual EI index is depicted in Table 4. Using the initial set of variables, two tests were conducted to reduce the number of variables composing the actual EI index. Ten variables significantly ( $p \leq 0.05$ ) predicted the unedited EI. However, these ten variables did not satisfactorily cover a broad range of ecosystem structure and function. A more liberal test was conducted ( $p \leq 0.12$ ), and seventeen variables significantly predicted the unedited EI. The final edited list of thirteen variables had four redundant variables eliminated from the list, percent high canopy cover, percent medium canopy cover, percent low canopy cover, and litter biomass. The total plant canopy cover variable and the plant canopy diversity variable were thought sufficient to characterize the plant canopy. Percent leaf litter cover was retained as a variable instead of litter biomass. Using this final edited list of variables an edited actual EI index was created. Grid unit 12 from 1995, a forested riparian site was selected as the base reference grid unit for the valley bottom area on the basis of having the highest actual EI index score.

The process of selecting variables for the valley bottom referenced EI index is depicted in Table 5. Using the initial set of variables, two tests were conducted to reduce the number of variables composing the actual EI index. Fourteen variables significantly ( $p \leq 0.05$ ) predicted the unedited EI. These fourteen variables did not satisfactorily cover a broad enough range of ecosystem structure and function.

**Table 4.** Variables measured in the process of creating the valley bottom actual EI index, which was used to determine the valley bottom base reference grid unit.

| <u>original list of variables for assessing valley bottom EI with absolute variable scores</u> |                               |                         |                             |
|------------------------------------------------------------------------------------------------|-------------------------------|-------------------------|-----------------------------|
| bare soil                                                                                      | plant morphological diversity | arthropod taxons        | root biomass                |
| basal vegetation cover                                                                         | plant species richness        | soil potassium          | standing live plant biomass |
| rock or pavement                                                                               | weeds                         | total soil nitrogen     | standing dead plant biomass |
| moss cover                                                                                     | plant canopy diversity        | soil organic matter     | litter biomass              |
| litter                                                                                         | soil nitrate/ total nitrogen  | soil carbon/ nitrogen   | water infiltration rate     |
| downed wood                                                                                    | live/ litter biomass          | soil phosphorus         | soil bulk density           |
| animal feces                                                                                   | low canopy cover              | soil nitrate            | soil respiration rate       |
| canopy cover                                                                                   | medium canopy cover           | high canopy cover       | mammal taxons               |
| <u>list of significant variables <math>p &lt; 0.05</math></u>                                  |                               |                         |                             |
| rock or pavement                                                                               | root biomass                  |                         |                             |
| litter                                                                                         | water infiltration rate       |                         |                             |
| canopy cover                                                                                   | soil respiration rate         |                         |                             |
| low canopy cover                                                                               | plant morphological diversity |                         |                             |
| medium canopy cover                                                                            | plant canopy diversity        |                         |                             |
| <u>list of variables <math>p &lt; 0.12</math></u>                                              |                               |                         |                             |
| rock or pavement                                                                               | high canopy cover             | litter biomass          | soil phosphorus             |
| litter                                                                                         | low canopy cover              | water infiltration rate | soil nitrate                |
| downed wood                                                                                    | medium canopy cover           | soil bulk density       | plant canopy diversity      |
| canopy cover                                                                                   | root biomass                  | soil respiration rate   | plant species richness      |
| plant morphological diversity                                                                  |                               |                         |                             |
| <u>edited list of variables to use in calculating absolute EI</u>                              |                               |                         |                             |
| rock or pavement                                                                               | plant canopy diversity        | litter biomass          | soil phosphorus             |
| litter                                                                                         | plant species richness        | water infiltration rate | soil nitrate                |
| downed wood                                                                                    | canopy cover                  | soil bulk density       | soil respiration rate       |
| plant morphological diversity                                                                  |                               | root biomass            |                             |

The more liberal test ( $p \leq 0.12$ ) was conducted and sixteen variables significantly predicted the unedited EI. The final edited list of thirteen variables had three redundant variables eliminated from the list, percent high canopy cover, percent medium canopy cover, and litter biomass. The variables listed at the bottom of Table 5, cover the three basic

ecosystem functions and ecosystem structure, but like in the upland referenced EI index, macro arthropods, and mammals were not significant in composing the overall index score.

**Table 5.** Variables measured in the process of creating the valley bottom referenced EI index, which was used to determine rankings of valley bottom plots.

**original list of variables for assessing valley bottom EI**

|                          |                               |                       |                             |
|--------------------------|-------------------------------|-----------------------|-----------------------------|
| % bare soil              | plant morphological diversity | # arthropod taxons    | root biomass                |
| % basal vegetation cover | plant species richness        | soil potassium        | standing live plant biomass |
| % rock or pavement       | % weeds                       | total soil nitrogen   | standing dead plant biomass |
| % moss cover             | plant canopy diversity        | soil organic matter   | litter biomass              |
| % litter                 | soil nitrate/ total nitrogen  | soil carbon/ nitrogen | water infiltration rate     |
| % litter                 | live/ litter biomass          | soil Olsen Phosphorus | soil bulk density           |
| % animal feces           | % low canopy cover            | soil nitrate          | soil respiration rate       |
| % canopy cover           | % medium canopy cover         | % high canopy cover   | # mammal taxons             |

**significant variables to .05 p**

|                               |                         |                        |
|-------------------------------|-------------------------|------------------------|
| % rock or pavement            | % high canopy cover     | soil bulk density      |
| % litter                      | % medium canopy cover   | soil carbon/ nitrogen  |
| % downed wood                 | litter biomass          | plant species richness |
| % canopy cover                | water infiltration rate | % weeds                |
| plant morphological diversity |                         | plant canopy diversity |

**variables with  $r^2 > .1$**

|                     |                       |                         |                               |
|---------------------|-----------------------|-------------------------|-------------------------------|
| % rock or pavement  | % medium canopy cover | water infiltration rate | plant morphological diversity |
| % litter            | root biomass          | soil bulk density       | plant species richness        |
| % canopy cover      | litter biomass        | soil carbon/ nitrogen   | % weeds                       |
| % high canopy cover | % downed wood         | total soil nitrogen     | plant canopy diversity        |

**edited list of variables**

|                     |                        |                         |                               |
|---------------------|------------------------|-------------------------|-------------------------------|
| % rock or pavement  | plant canopy diversity | water infiltration rate | plant morphological diversity |
| % litter            | root biomass           | soil bulk density       | plant species richness        |
| % canopy cover      | litter biomass         | soil carbon/ nitrogen   | % weeds                       |
| total soil nitrogen | % downed wood          |                         |                               |

To more clearly understand the process of creating the valley bottom EI index, Figure 9 is presented showing grid unit rankings based on the actual EI index scores. The absolute EI

scores based on the reduced number of parameters showed a continuum of EI scores where the three forested riparian plots had the highest scores and the commercial and industrial grid units had the lowest scores (Figure 9). Based on this ranking, a forested riparian plot was selected as the valley bottom base reference site for the referenced approach.

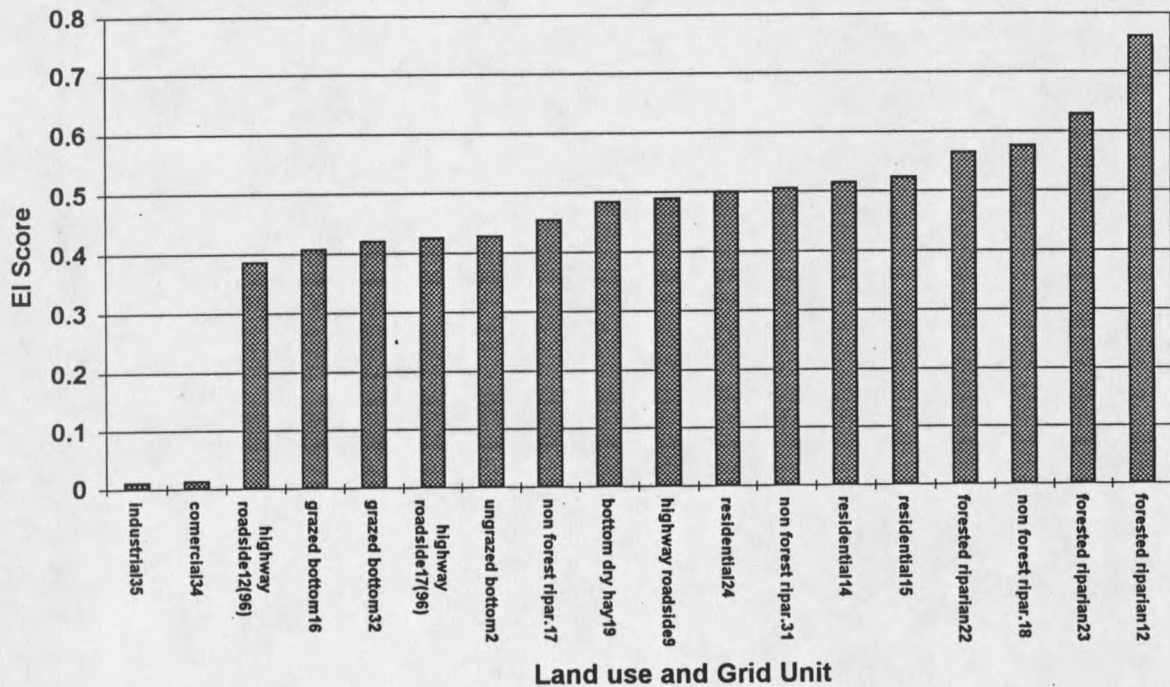


**Figure 9.** Ranking by actual EI of valley bottom grid units determined the valley bottom base reference plot, the highest-ranking grid units.

### EI Scores for Valley Bottom Grid units

Ranking of valley bottom plots by the referenced EI index score is shown in Figure 10. The three forested riparian plots rank highest followed by the non forested riparian and residential plots. The commercial and industrial plots rank lowest. There is an apparent discontinuity between the commercial and industrial plots and the rest of the valley bottom

plots. However, there were no cultivated land uses measured in the valley bottom. EI scores from cultivated plots may have filled in the gap in EI index score between the non irrigated hay plot and the commercial land use type.

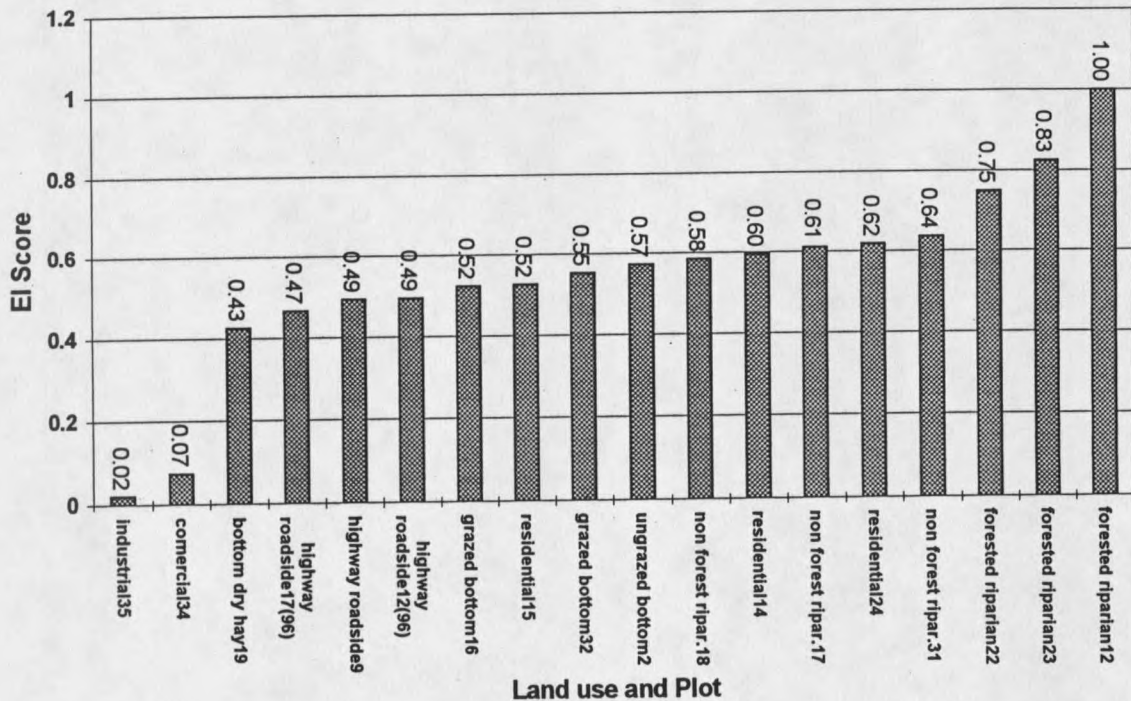


Figure 10. Ranking by referenced EI of valley bottom grid units.

### EI Scores for Valley Bottomland Use Classes

The ranking by referenced EI index scores for each valley bottomland use class is displayed in Figure 11. The commercial/industrial combined land use class ranked lowest and the forested riparian land use class ranked highest. The residential land use class ranked third behind non forested riparian and had a nearly identical score. This result occurred in spite of the pavement and houses that were present in residential areas.

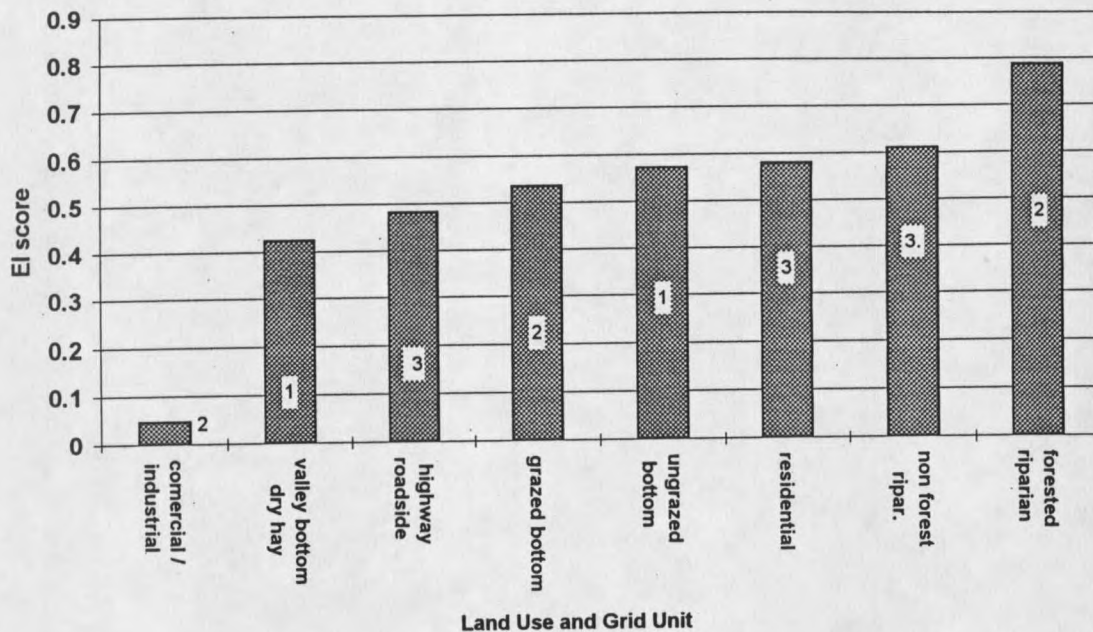


**Figure 11.** Ranking by referenced EI of valley bottom land use classes using averaged scores from 1995 and 1996 samples.

### **GIS Maps of Land Use and EI**

The mosaic of land uses was mapped from aerial photos for 1965, 1979, 1984, and 1990 (Figures 12-15). Land use patterns were mapped from field observations in 1994, 1995, and 1996 (Figures 16-18). In 1965 there were still large areas of native shrub range in the upland that had not been plowed and planted to wheat (Figure 12). Irrigation center pivots appeared in 1979 and more land changed to wheat production from native shrub range. Interstate highway 90 was also completed in 1979 (Figure 13).



Figure 12. Land use mosaic in 1965.

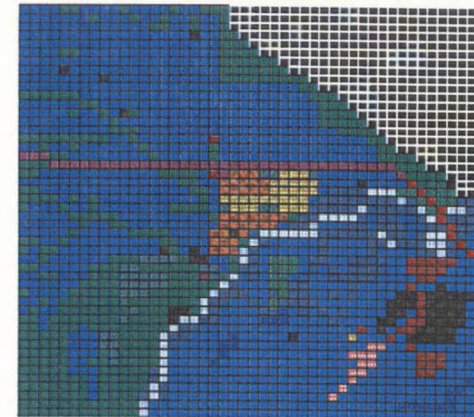


Figure 13. Land use mosaic in 1979.

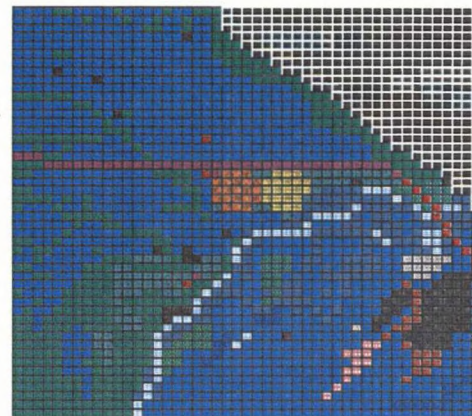


Figure 14. Land use mosaic in 1984.

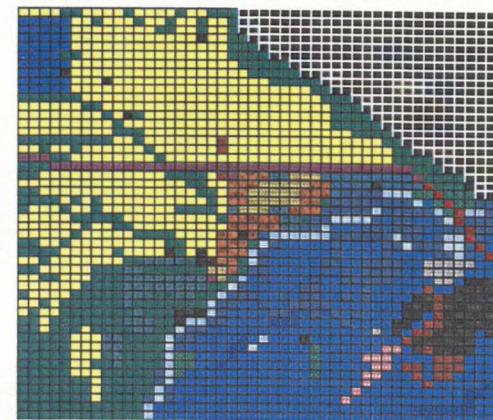


Figure 15. Land use mosaic in 1990.

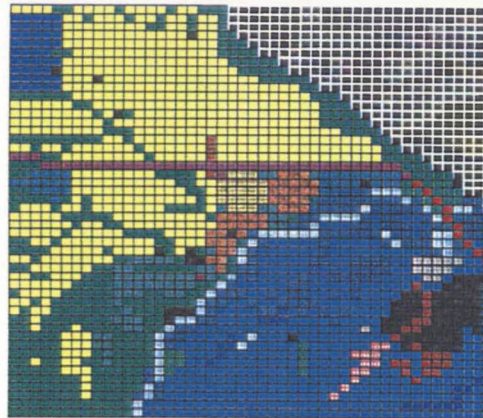


Figure 16. Land use mosaic in 1994.

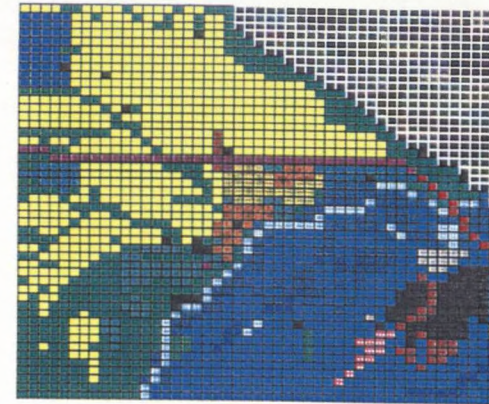


Figure 17. Land use mosaic in 1995.

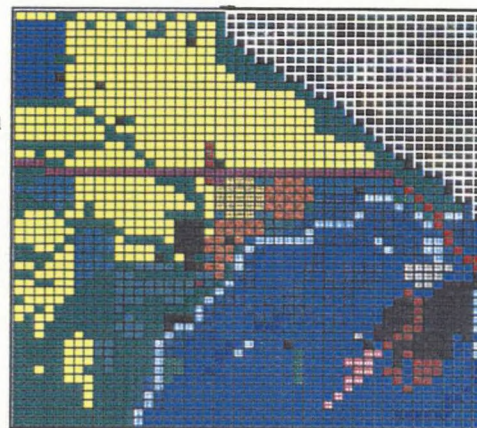


Figure 18. Land use mosaic in 1996.

The maximum extension of cultivated farmland occurred in 1984. The feedlot near town changed from industrial land use class to abandoned feedlot (Figure 14). The Conservation Reserve Program (CRP) was established in 1986 and a large proportion of the study area changed from dry land wheat farming to CRP and is evident in the 1990 map (Figure 15). Commercial development continued at the highway interchange, and a few scattered rural houses appeared in 1994 (Figure 16). The only changes in land use in 1995 were a few new rural houses (Figure 17). In 1996, some land was taken out of CRP and turned into seeded range. Other CRP land was developed into a subdivision (Figure 18).

Although the EI indices for the upland and the valley bottom were developed separately, the EI scores for each land use class were plotted on the same maps. The range of scores was comparable between the valley bottom and upland areas because of the way that the EI indices were calculated, as similarity indices of scaled variables. When EI index scores were categorized, several land uses were grouped in the same EI category. Shrub range was grouped with upland highway roadside. CRP, seeded range, and upland dryland hay all were grouped in the same EI category. Residential and ungrazed valley bottom native range were grouped in the same EI category. For ease of interpretation, the color gradient of EI, on the map legend, goes from indigo at highest EI and follows the colors of the rainbow to red at lowest EI.

In order to create a single over-all EI value for the study area, the EI index scores for each map unit were summed. In 1965, the over-all EI of the study area was 1052. The relative proportions of land in dryland wheat production and shrub range were the major influences on EI (Figure 19). The overall EI stayed about the same (1051) in 1979.

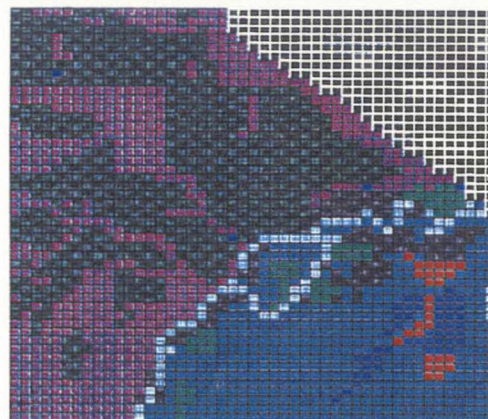
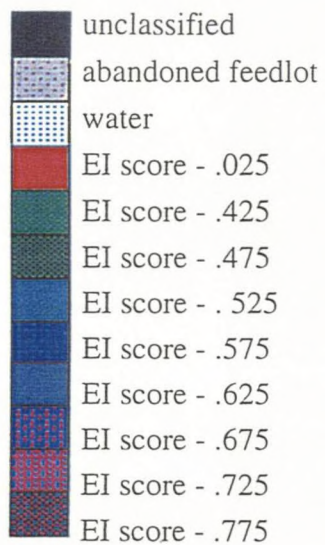


Figure 19. 1965 over-all EI = 1052.

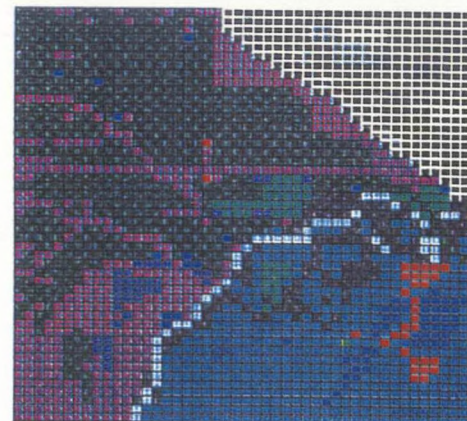


Figure 20. 1979 over-all EI = 1051.

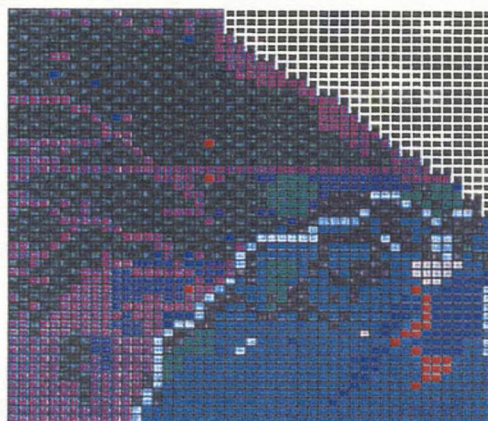


Figure 21. 1984 over-all EI = 1051.

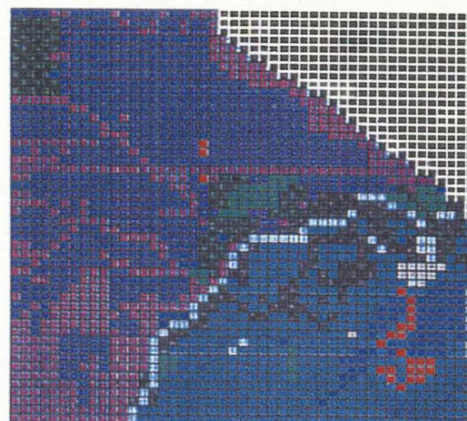
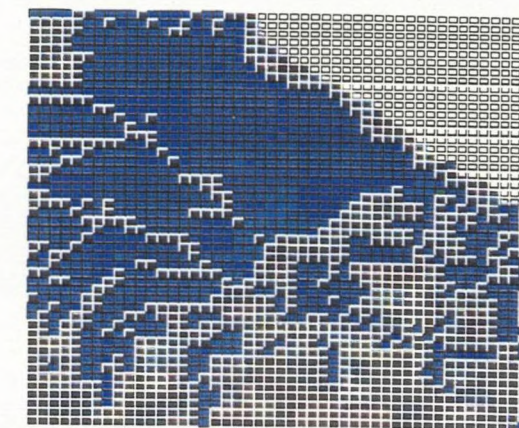
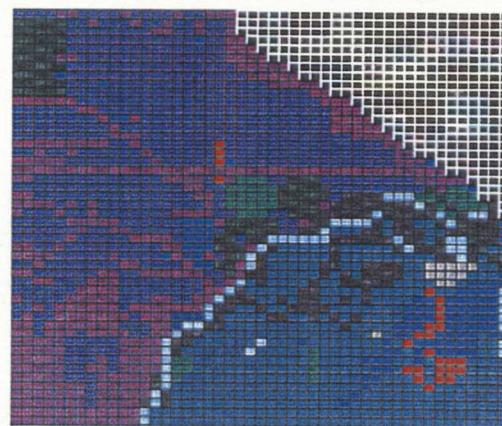
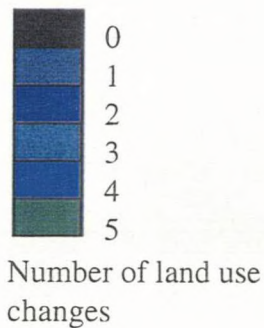
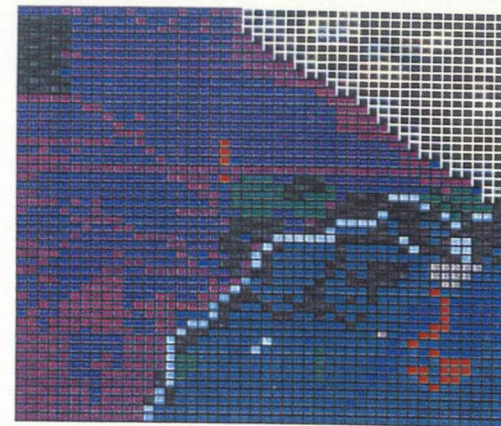
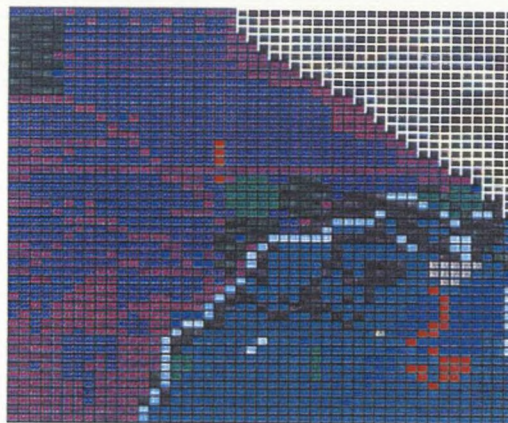
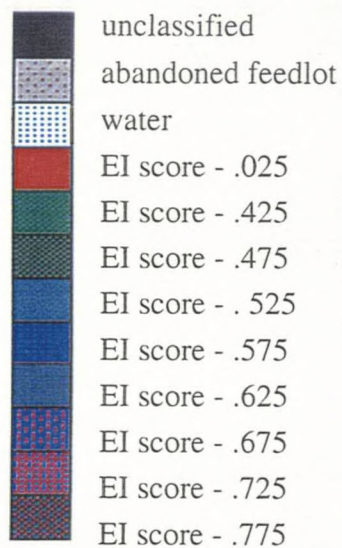


Figure 22. 1990 over-all EI = 1165.



The loss of native shrub range was offset by the conversion of some cultivated farmland to highway roadside. The upland highway roadside ranks in the same EI category as native shrub range, but the valley bottom highway roadside ranks lower than the native valley bottom range (Figure 20). The overall EI remained the same, 1051, in the 1984 map (Figure 21). In the 1990 map, the conversion of most of the dryland wheat fields to CRP dramatically raised the overall EI to 1165 (Figure 22). In 1994 the overall EI changed slightly to 1167 as irrigated alfalfa is rotated to irrigated wheat (Figure 23). The overall EI did not change in the 1995 map (Figure 24). The new subdivision had minimal effect on the overall EI in 1996. EI changed to 1166 (Figure 25).

The overall EI of the study area for each year, along with the number of sample grid units designating each EI index score category are shown in Table 6. The only significant change in EI coincides with the introduction of CRP between 1984 and 1990. Overall EI increased in 1990 to 1165 from 1051.

The number of land use changes experienced in each sample grid unit is shown in Figure 26. The center pivot irrigated units and the area surrounding the interchange of interstate highway 90 and US highway 287 showed the greatest number of changes. Results from correlation analysis (Steel and Torie, 1980) between EI of each grid unit sampled; and the number of land use changes, were not significantly different from 0 ( $r = 0.121$ ) at  $p = 0.05$  (Figure 27).

**Table 6.** The yearly overall EI for the study area was calculated by multiplying each EI category by the number of sample grid units apportioned to that category.

| EI category          | Number of sample grid units in each category |               |               |               |               |               |               |
|----------------------|----------------------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|
|                      | 1965                                         | 1979          | 1984          | 1990          | 1994          | 1995          | 1996          |
| 0.78                 | 104                                          | 131           | 132           | 130           | 130           | 129           | 129           |
| 0.73                 | 508                                          | 416           | 399           | 401           | 400           | 400           | 400           |
| 0.68                 | 0                                            | 37            | 70            | 641           | 644           | 643           | 631           |
| 0.63                 | 22                                           | 22            | 22            | 22            | 22            | 22            | 22            |
| 0.58                 | 51                                           | 64            | 82            | 83            | 86            | 90            | 102           |
| 0.53                 | 426                                          | 433           | 397           | 410           | 408           | 405           | 405           |
| 0.48                 | 657                                          | 682           | 671           | 96            | 116           | 116           | 116           |
| 0.43                 | 55                                           | 23            | 37            | 20            | 20            | 21            | 21            |
| 0.38                 | 0                                            | 29            | 20            | 24            | 0             | 0             | 0             |
| 0.33                 | 0                                            | 0             | 0             | 0             | 0             | 0             | 0             |
| 0.28                 | 0                                            | 0             | 0             | 0             | 0             | 0             | 0             |
| 0.23                 | 0                                            | 0             | 0             | 0             | 0             | 0             | 0             |
| 0.18                 | 0                                            | 0             | 0             | 0             | 0             | 0             | 0             |
| 0.13                 | 0                                            | 0             | 0             | 0             | 0             | 0             | 0             |
| 0.08                 | 0                                            | 0             | 0             | 0             | 0             | 0             | 0             |
| 0.03                 | 28                                           | 32            | 22            | 25            | 26            | 26            | 26            |
| <b>Study Area EI</b> | <b>1051.8</b>                                | <b>1051.4</b> | <b>1050.7</b> | <b>1164.6</b> | <b>1167.1</b> | <b>1166.8</b> | <b>1165.6</b> |

### Discussion

Soil respiration, live and dead standing crop, percent undesirable plants, mammal presence, macro-arthropod presence, and percent moss cover were indicators previously assumed to be important to EI (Buyanovsky, et al., 1987, Anderson, 1982, Woodley, 1993, Singh et al., 1975) but were not significant in composing either the upland or the valley bottom EI index. Their exclusion from the EI index either gave insight into the ecology of the study area or illuminated some of the difficulties of on farm research. Soil respiration was not a significant component of upland EI. High soil respiration rates could

indicate a high level of soil microbes present, but also indicate an increased potential to lose soil organic material from the system which under some circumstances could be ecologically detrimental (Doran et al, 1996). Temporal variation or variation in soil moisture or soil nutrients (Weaver and Forcella, 1979, Zwart and Brussaard, 1991) over the sampling season may have had an additional effect on microbial activity. Recent soil disturbance, in the form of plowing can also increase microbial activity which can confound results.

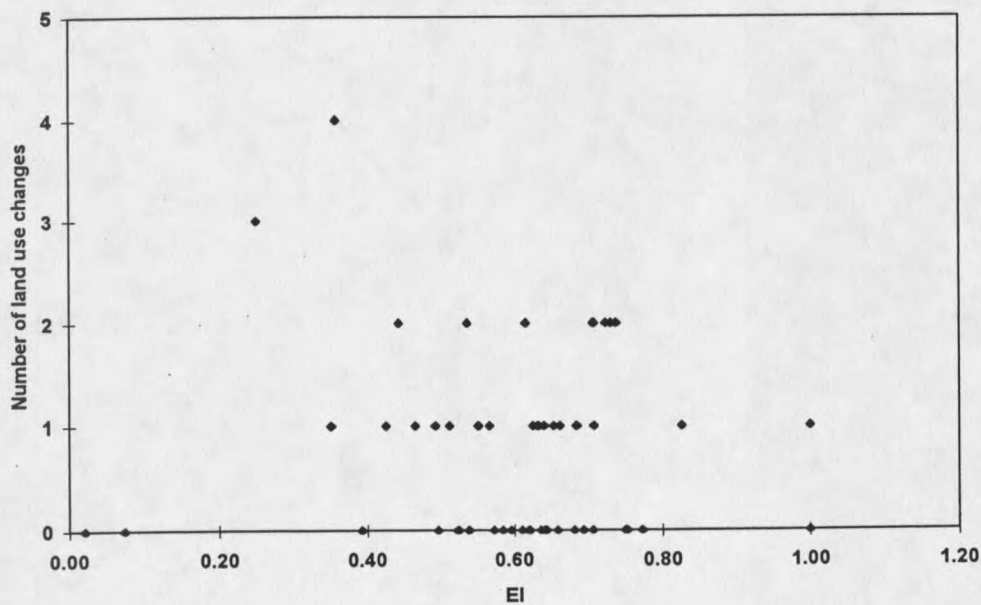


**Figure 27.** The number of land use changes versus EI among sampled grid units.

Clipping weights of live and standing dead vegetation in actively managed agricultural grid units was not a useful measure of productivity in this study. During the course of the growing season, fields were either grazed, mowed, harvested, mature, or in various stages

of growth when they were sampled. Therefore, comparison of productivity between grid units was problematic.

Percent of exotic plants (weeds) in the vegetation cover can have different ecological interpretations. Perhaps many weeds could be a sign of a recovering ecosystem which may imply high resiliency and subsequently high EI. Land with a low percentage of weeds may be ecologically intact and functioning with all niches filled by native species or it may be subjected to agricultural practices (herbicides) that while eliminating undesirable plant species, also reduced species diversity and therefore decreased EI. "Percentage undesirable species" was significant as a component of valley bottom EI but not upland EI where high disturbance agriculture was practiced.

Mammal presence, measured by direct observation and presence of scat, was so minimal that no trend was detected relative to EI in the study area.

Sampling for macroarthropods as an EI relevant parameter was subject to daily variability due to temperature, and therefore was not selected as an important parameter. A possible alternative method for sampling macro arthropod abundance would be to sample with a sweep net. Sampling would need to occur at all grid unit locations over a three or four day period at the end of July. Temporal variation would be eliminated, and a sweep net would cover a greater spatial range of habitat for macro arthropods.

Percent moss cover was significant in the upland EI but not in the valley bottom EI. Moss was ubiquitous in the valley bottom but appeared to decrease in response to increases in soil surface disturbance in the drier upland area.

Despite the difference in the processes of selecting variables for upland and valley bottom study areas, the two regions had similar parameters for their EI indices.

Differences can be attributed to inherent differences in soil moisture of the two landforms. Two seasons of sampling, as were conducted in the upland, should not be necessary to determine component variables of an EI index. If sufficient numbers of grid units could be sampled, multiple regression analysis with stepwise or backwards elimination would be sufficient to select variables.

Condensing the integrity of an agricultural field ecosystem down to one number has serious theoretical limitations. Numerous configurations of the ecosystem can give the same score and dimensionality is lost. However indices are valuable for conveying complex information to non-technical audiences (Messer, 1992). Assigning a single number to EI is convenient for relative ranking of sites, and allows use of the concept of EI as a tool in land use planning.

Of the nine resampled grid units not used as reference grid units, six had higher EI in 1995 and three scored higher in 1996. Figures 6, 7, and 8 all show different rankings for upland land uses depending upon the approach used to arrive at the EI index. Arguably, the year of sampling influences the ranking of land uses by EI. In future studies, because the sampling process has been streamlined, it may be possible to, and necessary to resample all plots in consecutive years to obtain useful rankings of EI. The simplest resolution to this dilemma appears to be to substantially increase sampling.

Several patterns in the rankings appear to support our EI index as being a meaningful useful tool. In upland areas, currently unplowed grid units rank above plowed grid units.

Continued soil disturbance and its resultant loss of soil and organic matter are conventionally associated with a system with less integrity (Doran et al, 1996). The Conservation Reserve Program (CRP) was instituted to improve the integrity of agroecosystems by reducing soil erosion associated with plowing marginal farmland. According to our EI ranking the program appears to be successful (at least in the short term) in improving the integrity of the land. In the long term, the lack of plant diversity may limit the adaptability of the CRP ecosystems to environmental changes such as fire or drought and EI could be reduced.

There was a dramatic increase in the overall EI when large tracts of land were converted from dryland wheat farming to CRP (Figure 28). The effect of this government program on overall EI far exceeded that of any other event in the study. The recognition that considerable marginal rangeland in the study area switched over to dryland wheat production as a result of government price supports, further dramatizes the relative effect of federal government policy on EI. The effects of population growth in the community on EI have been relatively minor. Since the inception of CRP, the population of Three Forks has increased by one third from 1,200 to 1,800 yet the overall EI has remained relatively constant (Table 6). From 1984 to 1996 the percentage of land apportioned to residential and commercial land uses increased by 1.02 percent. Up until the present, most residential and commercial developments have been concentrated near town and the highway interchange. Sprawling subdivisions of 20-acre "ranchettes" could present a different picture of EI. Though an average residential EI was not measured for upland areas, it is hypothesized that large subdivisions, which are proposed for upland areas, would have a

large effect on EI. Upland residential areas need to be surveyed for EI to better understand the impact of development.

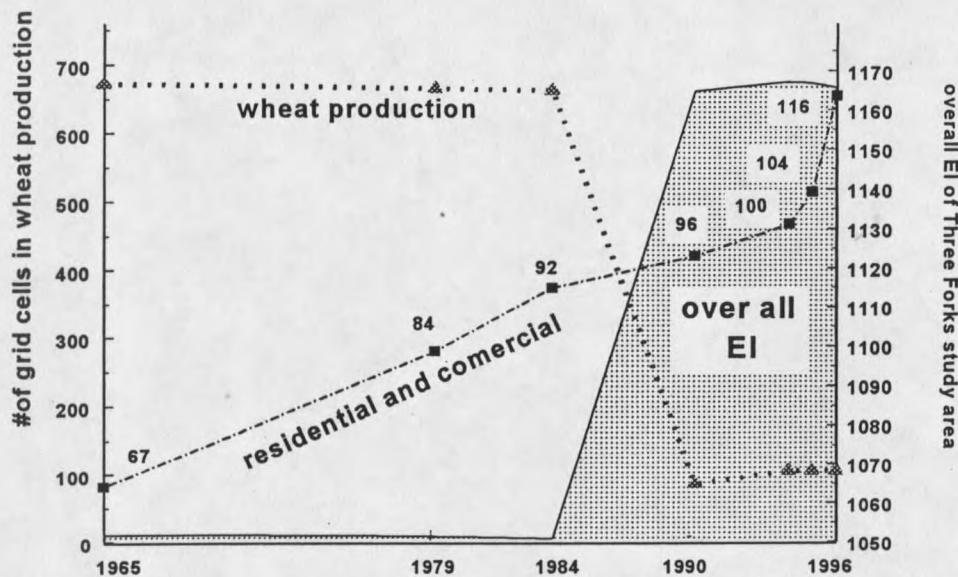


**Figure 28.** The change in the number of grid unit cells in wheat production and in residential and commercial land use classes over time compared to the overall EI of the study area.

Our definition of EI stated that a site with higher EI should continuously sustain the present level of land use. We therefore hypothesized that cells with higher EI should have changed land use less. We did not find this hypothesis supported by the data. Most likely the time scale at which EI becomes important for management purposes is longer than our study period of 32 years. Other confounding factors about which we had no knowledge were undoubtedly present. Our aerial photos may not have showed some changes in land use. Although we stratified the study area by landform, a relationship may have been

present between land capability class and number of land use changes. For example a field that has shallow rocky saline soil might go through a number of land use changes as the owners experiment with ways that they can exploit it. A field with deep loam soil may stay in crop production for a long time because it produces so well.

In the upland, highway roadside land use scored highest, the native sagebrush range scored second highest, and the parking lot of the flourmill scored the lowest. These end points of the EI spectrum were what we expected before the project was started. The roadside plots received the benefit of run-off water from the highway, were mowed once a year, with the grass clippings left on site, were relatively undisturbed and had a uniform management unlike the range grid units; these reasons are most likely why upland roadside grid units had a higher average EI than native range grid units. The argument could be made that in dry regions, the ability of an ecosystem to capture and retain water (the primary limiting factor) could be the best measure of EI.

The highway roadside was the only land use class for which we were able to obtain multiple sample repetitions in both the upland and valley bottom areas. Highway roadside ranked in sixth place among valley bottomland use classes and first among upland land use classes. One explanation of this result is that valley bottom sites were not water limited therefore the response of increased EI due to increased water run-off that was observed in upland roadsides was undetectable in the valley bottom. The difference in rank of upland highway sites versus valley bottom sites suggests that it may be better for the overall EI of the study area to locate future highways in the upland area.

Two valley bottom highway sites were sampled in 1996 although the valley bottom reference grid unit was not resampled in 1996. In the referenced EI rankings, the 1995 valley bottom highway grid unit and the two grid units from 1996 were all of similar value. The relative ranking by average EI score using all three sites was not different from that using only the 1995 grid unit EI.

The idea of applying ecosystem management to agriculture appears to be validated by our results. The EI index is basically a similarity index with the premise that there is an inherent organization of the base reference system that if mimicked will produce an agroecosystem of high integrity. Unplowed grid units, grid units of high plant species richness and grid units with low amounts of bare soil all ranked high in EI. Using only the criteria of maximization of EI to determine land use would result in a landscape of all grazed native range and mowed roadsides. This situation may or may not be advantageous to the integrity of the human community. Most likely, having diverse forms of production will benefit the economic stability of the community. A case could be made for optimizing the landscape diversity of a rural community. EI would be weighed against income potential and satisfaction with quality of life to determine the community structure and land use pattern that most favors community sustainability.

In the valley bottom areas, residential land use ranked relatively high despite the presence of significant amounts of pavement and buildings. The presence of a high plant canopy layer in the form of cottonwood trees (*Populus trichocarpa*), and high species diversity, similar to the reference forested riparian plot, contributed to this result.

Residential areas in Three Forks, through the efforts of individual landowners, were more

intensively managed for aesthetic appeal than were the commercial and industrial areas. The fact that all residential plots ranked higher than commercial and industrial plots may indicate that aesthetic value is important in determining EI. Regier (1993) proposed that there is a correlation between aesthetic appeal and EI. A potential result of relating EI to community integrity is that viewscape emerges as an important factor defining community integrity.

The concept of EI becomes more useful to an individual landowner when comparing land under the same general land use. For example, within the paradigm of being a wheat producer, there are ways of farming that would produce states of higher or lower EI. Fence line studies could assess the EI of conventional and alternative cropping practices. Monitoring of production and inputs over time and longevity of the agricultural operation would test the hypothesis that EI is related to sustainability.

In the valley bottom, it is difficult to tell from examination of aerial photographs, whether or not the entire valley bottom may have been cottonwood forest at one time. The question arises whether another level of stratification would have been appropriate, and whether or not the EI index was biased towards forested areas. Certainly, all three forested riparian plots clustered at the high end of the EI scale. Forested riparian, non-forested riparian, and valley bottom native range were all grazed by cattle (the land use was the same but the vegetation cover was different). If there was a significant difference between the average EI scores of these three land use classes it may have been due to environmental variation. Insufficient sampling precluded the possibility of determining statistical differences in average EI between different land use classes. As with the upland

samples, the EI index was still valuable when comparing sites within the same land use category.

### Conclusions

The study area was selected based on its proximity to a small community and on its diversity of land uses that are generally representative of the Rocky Mountain Region. However, any conclusions drawn about the relative ranking of land uses must be limited to the region surrounding the study area. This conclusion is evident from the differences observed in the composition of the upland and valley bottom EI indices. Similar land uses in different environments will exhibit different EI rankings. Regional differences in cultural practices will also contribute to differences in EI rankings of land uses. What we have developed is a methodology for assessing EI in rural communities in the arid North Western United States. Our EI index may be useful for land use planners concerned with maintaining the EI of their rural communities. Producers comparing different cultural practices for sustainability may also benefit from this monitoring methodology. To this date we know of no other method that assesses EI of different land uses in agricultural rural communities.

The one issue that is hard to resolve is that of distinguishing between EI and background environmental variability or land capability. Excessive stratification of a study area would lead to difficulty in obtaining sample replications, and inapplicability of results for use as a planning tool. Ideally all variables selected for an EI index would be influenced by land use practices but have uniform values across the study area if the landscape was

subjected to uniform management. This situation does not occur in real life situations. Management within land uses varies by landowner, and soils vary across the study site. However, real patterns emerge from the EI data. In the upland, parking lots and plowed fields ranked at the low end of the EI spectrum and native range and mowed roadsides ranked at the high end. In the valley bottom, forested riparian areas were at the high end of the EI spectrum and commercial and industrial areas were at the low end.

The spread of results suggests that more sampling is necessary if any definitive rankings of EI by land use are to be made. Because of the time limitations on sampling that coincides with peak productivity in the plant communities, a quick method of assessing EI is essential so that sufficient sites can be sampled.

The strongest conclusion to come out of this study was that changes in federal government policy had more effect on EI of the study area than did growth of the community. The development of the EI index could serve as a tool to empower local communities enabling them to assess the environmental impacts of externally imposed economic regimens.

## Chapter 2

### TESTING A RANGE MONITORING METHOD THAT USES VISUAL ESTIMATES FOR ASSESSING RANGELAND HEALTH

#### Introduction

Current interest in ecosystem health has fostered changes in perspective about how range condition should be assessed (Mouat, et al., 1992; Campbell et al., 1994; Savory, 1988). In 1994, the National Research Council published the landmark book *Rangeland Health* (1994). The authors surveyed the history of range monitoring and proposed an approach for evaluating range condition that reflects current values and ecological thinking.

Rangeland health was defined as the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained. Assessment of rangeland health was based on the preponderance of evidence of multiple criteria. These criteria were grouped in three categories of ecosystem function: soil stability and watershed function, integrity of nutrient cycles and energy flows, and presence and functioning of recovery mechanisms (National Research Council, 1994).

Visual estimates have been routinely incorporated in range monitoring to aid in rapid assessment of range condition (Jensen, et al., 1992). The National Research Council proposed a suite of visual estimate indicators in a rangeland health evaluation matrix and called for research to interpret those indicators in terms of ecosystem function. We evaluated a version of the *Rangeland Health* evaluation matrix for interpretability, repeatability, and significance of correlation to an approach using actual in the field measurements.

There has been a lack of on the ground application of the concept of ecosystem health to land management in agroecosystems (McKenzie, et al., 1992). Developing an understanding of ecosystem health 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, physical inputs must be replaced by more intensive management. Monitoring tools need to be developed to sustain and make more efficient use of resources (National Research Council, 1994; Meyer, et al., 1992).

### **Literature Review**

There is a growing body of literature that examines the selection of 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: 1) 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.

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 ecosystem integrity indicators based on a societal values perspective. They identified ecosystem integrity assessment questions and indicators that determined quality of air, water and soil, ecosystem productivity, and biodiversity.

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 measurement 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, et al., (1993) state that ecological indicators should be ecologically meaningful, indicate changes at the community scale, be measured meaningfully 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).

Actual in the field measurement of soil health is much more developed than is field measurement of rangeland ecosystem health. Various researchers have published their lists of minimum data sets for indicators of soil health (Doran and Parkin, 1994; Larsen and Pierce, 1994; Karlen and Stott, 1994). In rangeland ecosystems where vegetation is regularly grazed, soil health measures can play a large role in determining the overall health of the ecosystem.

This study evaluates the rangeland health monitoring method being developed by Orchard (1994) of Land EKG, a private rangeland consulting firm. Orchard's approach and that of Pellant (1996) are both based on the methodologies suggested in National Research Council (1994).

The principle behind a rangeland evaluation method based on visual estimates is to provide an easy to use and easy to interpret tool for land managers to monitor ecosystem health. Such a tool for rangeland health evaluation will be used often enough to provide a well-organized base of information from which to make land management decisions. Carrying out visual estimates of vegetation and soil surface condition in a systematic way provides an opportunity for land managers to be looking at the land in a critical, documentable and repeatable fashion. Additionally, no single indicator alone is sufficient for characterizing ecosystem function or rangeland health. The assessment of rangeland health must be based on the preponderance of evidence obtained from the site (National Research Council, 1994).

### Materials and Methods

Sampling took place during June and July of 1995 and 1996. The study was conducted in a twenty five square mile area surrounding Three Forks, Montana. The area was stratified by landform into two regions, upland and valley bottom. Soils are silt loams from loess parent material in the upland area, and loams to sandy loams from alluvial 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 in order to encounter a wide variation in vegetation and soil surface conditions (Table 7). The following are general descriptions of the vegetation and land uses of the sample plots. The upland native range plots were dominated by blue gramma (*Bouteloua gracilis*), and sagebrush (*Artemisia tridentata*). In 1986 the Conservation Reserve Program (CRP) went into effect, converting wheat fields to perennial grasslands. Plots in CRP were mostly planted to crested wheatgrass (*Agropyron cristatum*) or a mixture of crested wheatgrass and alfalfa (*Medicago sativa*). In 1996 some CRP land was taken out of the government program and grazed. Plots in former CRP lands were classified, for purposes of this study, as seeded range. One seeded range plot, was sampled in 1995 and was in a pasture planted to Russian wild rye (*Elymus giganteus*). One upland dryland hay field plot was in a field of mixed native species, alfalfa (*Medicago sativa*) and crested wheatgrass (*Agropyron cristatum*) the other hay field plot was in a field planted with a mixture of

Russian wild rye (*Elymus giganteus*) and crested wheatgrass (*Agropyron cristatum*). The irrigated wheat plot was in a center pivot irrigated field. The wheat and fallow plots were in fields that are rotated each year.

The historic use of the valley bottom sites has been cattle pasture. Forested riparian plots were in cottonwood (*Populus angustifolia*) groves along the Jefferson River. Non forested riparian plots were in low lying grassland areas subject to periodic flooding dominated by Kentucky bluegrass (*Poa pratensis*), foxtail barley (*Hordeum jubatum*), and Baltic rush (*Juncus balticus*). Plots classified as highway roadside were alongside Interstate Highway 90, and planted with crested wheatgrass (*Agropyron cristatum*). The ungrazed plot was in the infield of the local airport that has been fenced off for at least the last 30 years. Grazed valley bottom range plots were in fields dominated by blue gramma (*Bouteloua gracilis*) and Western wheatgrass (*Agropyron smithii*).

**Table 7.** The number of plots sampled within each land use class for each year.

| Upland 1995      | no. of plots | Upland 1996  | no. of plots | Valley bottom 1995     | no. of plots |
|------------------|--------------|--------------|--------------|------------------------|--------------|
| CRP              | 5            | CRP          | 5            | Forested riparian      | 3            |
| Hay              | 2            | Hay          | 2            | Highway roadside       | 1            |
| Shrub range      | 3            | Shrub range  | 6            | Grazed range           | 2            |
| Wheat            | 1            | Seeded range | 2            | Non forested riparian  | 3            |
| Fallow           | 1            |              |              | Ungrazed valley bottom | 1            |
| Highway roadside | 2            |              |              |                        |              |
| Irr. wheat       | 1            |              |              |                        |              |

The study area was divided into a grid of 47 by 48 cells of approximately 6.4 acres in size. Sampling was conducted to characterize ecosystem integrity within particular 6.4 acre cells (plots). Fifteen plots in the upland and ten plots in the valley bottom were

acre cells (plots). Fifteen plots in the upland and ten plots in the valley bottom were sampled in 1995. Fifteen upland plots and one valley bottom plot were sampled in 1996. A total of ten CRP, nine shrub range plots, four hay field plots, two seeded range plots, two upland highway roadside plots, one wheat field plot, one fallow field plot, and one irrigated wheat field plot were sampled in the upland over the two years. Three forested riparian, three non-forested riparian, two grazed range, one highway roadside, and one ungrazed range plot were sampled in the valley bottom.

To sample a given plot, the surveyor walked a diagonal transect across the 6.4 acre plot area, throwing down a 0.5 meter<sup>2</sup> sampling frame at 30 pace intervals. Five frames were sampled per surveyor per plot. Location of the sample plot and the diagonal transect were determined from an aerial photograph of the study area with gridlines laid over the top.

The visual estimate evaluation scorecard is presented in Figure 29. Fifteen visually estimated variables representing ecosystem function were evaluated: percent soil cover, pedestalling, rill and sheet erosion, and soil crusting represent soil stability and water cycling; percentage of desirable plants, plant age class distribution, plant vigor, and plant germination sites represent recovery mechanisms; litter breakdown, litter abundance and distribution, plant spacing, plant species diversity/roots, plant canopy distribution, live plant canopy abundance, and herbivore utilization represent nutrient cycling and energy flow (Orchard, 1994). Space is provided to enter a score from zero to five for each variable for each frame sampled. The scores from each frame for each variable were totaled and averaged at the bottom of the page.

Criteria for scoring each variable are described in Figures 30 and 31. The value of each variable was estimated by observing the area within the frame. Descriptions of vegetation and soil characteristics corresponding to different degrees of function of each ecosystem variable are ranked from zero to five, with five indicating the healthiest state (Orchard, 1994). Samplers were instructed to interpolate between the vegetation and soil descriptions in Figures 30 and 31 in order to score each variable as accurately as possible.

field monitoring form, © Orchard 1994

| steps<br>between<br>frames | soil stability &<br>water cycling |             |             |               | recovery<br>mechanisms |                  |             | nutrient cycling &<br>energy flow |                  |                  |               |                   |              |               |             |
|----------------------------|-----------------------------------|-------------|-------------|---------------|------------------------|------------------|-------------|-----------------------------------|------------------|------------------|---------------|-------------------|--------------|---------------|-------------|
|                            | % cover                           | pedestaling | rills-sheet | soil crusting | desirable plants       | age distribution | plant vigor | germination sites                 | litter breakdown | litter abundance | plant spacing | spp. div. / roots | canopy dist. | canopy abund. | utilization |
| Frame 1                    |                                   |             |             |               |                        |                  |             |                                   |                  |                  |               |                   |              |               |             |
| Frame 2                    |                                   |             |             |               |                        |                  |             |                                   |                  |                  |               |                   |              |               |             |
| Frame 3                    |                                   |             |             |               |                        |                  |             |                                   |                  |                  |               |                   |              |               |             |
| Frame 4                    |                                   |             |             |               |                        |                  |             |                                   |                  |                  |               |                   |              |               |             |
| Frame 5                    |                                   |             |             |               |                        |                  |             |                                   |                  |                  |               |                   |              |               |             |
| total                      |                                   |             |             |               |                        |                  |             |                                   |                  |                  |               |                   |              |               |             |
| average                    |                                   |             |             |               |                        |                  |             |                                   |                  |                  |               |                   |              |               |             |

Figure 29. Field monitoring form for scoring visual estimates. Each variable is scored from 0-5 for each frame and the scores averaged for the plot.

# TRANSECT EVALUATION MATRIX ©Orchard 1984

|                  |                                                                                         |                                                                                                                                                 |                                                                                                   |                                                                     |
|------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| Living Organisms | Report any signs of life which has taken place in or within close distance to the frame | LARGE ANIMAL SIGN<br>Fresh or old: Cattle, Horse, Sheep, or Game <u>tracks</u><br><br>Fresh or old: Cattle, Horse, Sheep, or Game <u>manure</u> | SMALL ANIMAL<br>Fresh/old: Tracks, manure, burrows<br><br>BIRD<br>Fresh/old: nest, tracks, manure | INSECTS<br>Ants<br>Spiders<br>Hoppers<br>Beetles<br>Others<br>Worms |
|                  |                                                                                         |                                                                                                                                                 |                                                                                                   |                                                                     |

## SOIL STABILITY AND WATERSHED / CYCLE FUNCTIONING

|                                                                      | 0 pts                                                                                                                           | 1 pt.                                                                            | 2pts.                                                                                                | 3 pts                                                                     | 4 pts.                                                                   | 5 pt. |
|----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------|-------|
| Surface cover                                                        |                                                                                                                                 |                                                                                  |                                                                                                      |                                                                           |                                                                          |       |
| Pedestalling                                                         | Most plants and rocks pedestaled:<br><u>Many</u> bare roots                                                                     | Strongly elevated<br><u>Some</u> bare roots                                      | Elevated pedestals readily apparent on mature plants.<br><br>- <u>No bare roots</u>                  | Slight signs of pedestalling.<br>Some raised crowns                       | No evidence of pedestalling around plants or rocks                       |       |
| Rill / Gully and/or Scour / Sheet-erosion                            | Rills/scours actively expanding into small gullies<br>-OR-<br>large bare areas<br>-Major soil movement-<br>-Plant displacement- | Well defined rills are connected<br>-Some soil deposition or plant displacement- | Small slightly developed rills. Not fully connected<br>-OR-<br><u>Obvious patches</u> of bare areas. | Slight signs of rills & / or<br>Small bare patches                        | No evidence of rills or gullies<br>No evidence of bare areas or blowouts |       |
| Soil crusting<br>(If over 30% bare use the majority of exposed soil) | Mature capping densely crusted soil layer ≥ 1 cm.<br>May sound hollow                                                           | Crusted layers 1cm.                                                              | Thin, <u>recently formed</u> crusted soil surface                                                    | No crusting, -broken soil surface<br>-&/or-<br>light litter cover present | No crusting is evident<br>soil is covered w/ litter or plants            |       |

## RECOVERY MECHANISMS

|                         | 0 pts.                                                                                                                    | 1 pt.                                                          | 2 pts.                                                                                                                                                                        | 3 pts.                                                    | 4 pts.                                                                                                                                                                                | 5pts |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Desirable Plants        | > 50% <u>undesirable</u> plants within frame                                                                              | Many weeds but <u>less than 50%</u> composition                | Some obvious undesirable plants within frame                                                                                                                                  | Few weeds present                                         | Absence of undesirable plants within frame                                                                                                                                            |      |
| Age class distribution  | -Desirable plants old or deteriorating.<br><br>-No indication of plant reproduction success (including tillering)         | None or <u>Very</u> few young plants or tillers                | -Few signs of reproductive success for desirable plants<br><br>-Few young desirable plants<br><br>Some evidence of old plant tillering                                        | Numerous young plants or tillers                          | -desired pattern of age classes<br><br>-Several signs of plant reproduction success<br><br>-Desirable seedlings or new tillers readily apparent--                                     |      |
| Plant vigor             | Most plants show poor vigor<br><br>15% dead or dying plants                                                               | Several sick or weak desirable plants.<br><br>5% dead or dying | Some desirable plants developing abnormal growth form<br><br>-Overrested, overgrazed or droughted--<br>-Some plants lack vigor                                                | A <u>few</u> desirable plants lack vigor                  | All plants display normal and vigorous growth form                                                                                                                                    |      |
| Plant germination sites | Soil movement and/or crusting sufficient to inhibit plant germination and seedling establishment<br><br>No litter present | Patchy litter cover.<br><br>Poor seedling protection           | -Some recent and fragile crusts present.<br><br>-Indications of slight soil movement<br><br>-Some depressions and broken areas available for seed protection and soil contact | No crusting present<br>Good protection for seedling sites | Many germination sites present.<br>-Many depressions and broken areas available for seed protection and soil contact<br><br>Excellent seedling protection by litter or other material |      |

Figure 30. Scoring criteria for the visual estimates of soil stability and water cycling and recovery mechanisms.

| Brittleness (Bio-decay rate)                     |                                                                            |                      |                                                                              |                            |                                                                       |      |
|--------------------------------------------------|----------------------------------------------------------------------------|----------------------|------------------------------------------------------------------------------|----------------------------|-----------------------------------------------------------------------|------|
|                                                  | 0 pts.                                                                     | 1 pt.                | 2pts.                                                                        | 3pts                       | 4 pts                                                                 | 5 pt |
| Litter Breakdown<br>(Look outside of frame also) | -Matter is not incorporated into the soil                                  | Little decomposition | Moderate decomposition of litter.                                            | Moderately rapid breakdown | <u>Rapid</u> decomposition and incorporation of litter into the soil. |      |
|                                                  | Most organic matter is chemically oxidized<br><br>4 - 5 years to decompose | 3 - 4 year breakdown | -Matter is slowly incorporated into the soil<br><br>2 - 3 years to decompose | 1 year decomposition       | Almost all decay is biological<br><br>Decay rate 3 months or less     |      |

#### DISTRIBUTION OF NUTRIENT CYCLING AND ENERGY FLOW

|                                              | 0pts.                                                                                                                                          | 1pt.                                                         | 2 pts.                                                                                                                                                                                          | 3 pts.                                                                     | 4 pts                                                                                                                                                                      | 5 pts |
|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| Litter abundance and distribution            | Litter cover is absent<br><br>0-20%                                                                                                            | Light and patchy litter covering soil surface<br><br>20 -40% | Moderate amount of litter obvious patchy distribution.<br><br>40 - 80% cover                                                                                                                    | Much litter, Distribution somewhat patchy<br><br>60-80%                    | Relatively Uniform and abundant litter cover across frame<br><br>80 - 100% cover                                                                                           |       |
| Plant spacing                                | - Obvious large bare areas between clumps.<br>-Plants clumped or widely separated                                                              | Distinct bare areas                                          | -Plant distribution is fragmented<br>-Areas of bare ground present<br>- Fragmented crowns on bunch grass and mat forming plants                                                                 | Somewhat fragmented plant distribution<br>-uniform but light plant cover-- | -Few areas of bare ground<br>-Plants well distributed across the site,<br>-Uniform and dense cover--                                                                       |       |
| Species diversity AND / OR Root distribution | -None or few types of plants in the frame.<br><br>Basic monoculture.<br>1 - 2 spp<br><br>-Roots using small area of the available soil profile | 1 life form<br><br>2-4 spp                                   | -Several kinds of plants making up the plant community.<br><br>2 LIFE FORMS<br>grass/forb grass/brush brush/forb<br>4 - 6 spp.<br><br>-Absence of roots from portions of available soil profile | 3 life forms<br>Brush/Forbs/ grass<br><br>6 - 10 spp                       | -Many kinds of plants & other organisms (sign) making up the community.<br><br>3 or more life forms<br>more than 10 spp.<br><br>-Rooting throughout the available profile. |       |
| Canopy distribution                          | No canopy cover collecting solar energy.                                                                                                       | 1 layer of canopy cover                                      | Two canopy layers collecting sunlight.                                                                                                                                                          | 2-3 canopy layers in plant comm.                                           | 3 or more canopy layers collecting solar energy                                                                                                                            |       |
| Live canopy abundance (approx. shade)        | - 80-100% sunlight hits ground surface<br>-Almost no shade on ground surface                                                                   | 60% to 80% of sunlight hits ground.                          | -40 to 60% of the sunlight hits ground surface.<br>- 1/2 ground surface is covered with shade                                                                                                   | 20%-40% of sunlight hits ground surface                                    | -0-20% sunlight hits ground surface<br>-Much shade on ground surface                                                                                                       |       |
| Herbivory utilization (Consumer)             | No plants used by living organisms in the past 2 growing seasons                                                                               | Few plants used<br>1 of 4 plants recieved some use           | 50% of plants recieved some selective use<br>grazing/ browsing/ herbivory                                                                                                                       | Most plants recieve some use<br>3 of 4                                     | Uniform use of most plants                                                                                                                                                 |       |

Figure 31. Scoring criteria for the visual estimates of nutrient cycling and energy flow.

Comparisons were made with the following more rigorous empirical method to assess the meaningfulness of the visual estimates. At each sample plot a 150 meter baseline transect was laid down in the same location as the walking transect used for the visual estimate approach. Cross transects were placed at 50, 100, and 150 meters. Six, 0.5 meter<sup>2</sup> sampling frames were placed randomly along each cross transect. A pilot study and subsequent analysis of the running totals of the variances, determined the number of frames needing to be sampled for each of the measurements listed below.

*Plant Species Composition:* Within 18 sampling frames per plot, all plant species were identified. The percent cover by species was estimated visually within the sampling frame. The Shannon Weiner diversity index (Goldsmith, et al, 1986) was used to create a morphological diversity index from a classification of plant species present by life form. Plant species were classified as either annual forb, annual grass, perennial forb, perennial grass, biennial forb, perennial shrub, or tree. Whether the plant was a native, crop or introduced weed was noted to calculate percent undesirable plants. In cropped areas, both native and exotic weeds were considered undesirable; in native range sites, only exotic weeds were considered undesirable. Plant species richness was determined as the number of species found in the 6.4 acre sample plot in and outside of the sampling frames during the course of obtaining the complete suite of ecosystem measurements.

Above ground vegetation structure was characterized as the percent of canopy cover in three height classes: 0-0.5 m, 0.5-2.0 m and >2.0 m (Jensen, et al., 1992). Plant canopy diversity was calculated using the Shannon Weiner diversity index (Goldsmith, et al, 1986). Eighteen frames per plot were sampled.

*Standing Crop/ Above Ground Biomass:* All vegetation was clipped from a 25 percent area within each of six frames per plot, except for cropped areas where three frames per plot were clipped. Vegetation was separated into present year's (green) growth, previous years (standing dead) growth, and litter (stems not attached to the ground). Present year's growth was dried, weighed and recorded as an estimate of net primary productivity in the ecosystem (Singh, et al., 1975). Standing dead plant biomass, and litter were dried and weighed and recorded. In riparian woodlands, standing crop was estimated using plant stem diameter, height and allometric relationships (Boggs, 1984) if a shrub or tree fell within a sampling frame. Present year's production was estimated on shrubs overhanging a sample frame by removing leaves (Jensen, et al., 1992). The live to litter ratio was calculated from the average values of all frames sampled in a plot.

*Root Biomass:* Five systematically located (at tape marks along the edge of the frame) soil cores of 10 cm depth and 2 cm diameter, were taken within nine 0.5 m<sup>2</sup> sampling frames per plot to estimate root biomass. (Milchunas and Lauenroth, 1989, Bartos and Sims, 1974, Coffin and Lauenroth, 1991). The root core samples were washed, sieved in a # 35 soil sieve, and set to dry in a 50°C drying oven for 48 hours, then weighed. Results were expressed in grams of roots per m<sup>2</sup> in the top ten cm of soil.

*Soil Bulk Density:* A 10 cm deep, 5 cm diameter soil core was extracted adjacent to nine sample frames per plot and placed in a sealed soil sample bag. Each soil core was dried for 72 hours, and weighed. Bulk density was calculated as grams per cm<sup>3</sup>.

*Water Infiltration Rate* was measured by pounding a sixteen cm diameter PVC ring five cm into the ground adjacent to nine sampling frames per plot. The infiltration of five

cm of water poured into the ring was timed. If infiltration time exceeded sixty minutes, the time was noted as sixty-five minutes.

*Soil Temperature at 50 cm Depth:* A shallow pit was dug near six sampling frames per plot and a soil thermometer stuck in the side of the soil profile at 50 cm beneath the surface.

*Soil Nutrient Analysis:* Soil samples from the bulk density cores were pooled from all nine cores sampled in a plot and analyzed for soil organic matter, total Kjeldahl nitrogen, Olsen phosphorous, potassium, and nitrate in the Montana State University Soil Analytical Lab.

*Soil Respiration:* The open end of a one gallon tin (respirometer) can with a diameter of 15.5 cm was pounded in the ground 2 cm deep. A petri dish with 0.50 ml of 1M KOH solution was placed on a wire stand inside the tin can where the soil surface was cleared of vegetation near nine sampling frames per plot. The KOH solution was left exposed for 24 hours to absorb evolved  $\text{CO}_2$ . At each plot, control petri dishes were placed inside cans sealed at both ends. The exposed solution samples were taken back to the lab in sealed jars, and titrated with 0.1M HCl (Lundegardh, 1927, Anderson, 1973, Gupta and Singh, 1976). The net evolved  $\text{CO}_2$  per  $\text{m}^2$  per twenty four hours was calculated according to Anderson (1982).

*Mammal and Arthropod Taxons Present:* Pellet piles and burrows within 18 sampling frames per plot were identified to finest taxonomic level possible and the number of distinct taxons present in each plot was noted. The number of different macro arthropod taxons observed inside 18 sampling frames per plot was recorded. The macro arthropod

net sweep was made by a sampler taking 100 ground level sweeps of an insect collecting net along the baseline transect, taking one step between each sweep. Contents of the collecting net were emptied into a zip-lock bag and the number of different arthropod taxons observed was recorded.

Each visual estimate was compared with all field measurements using correlation analysis (Steel and Torrie, 1980). The significant correlations between visually estimated variables and measured variables were listed for upland samples in 1995 and 1996, and for valley bottom samples in 1995.

Three student research technicians were trained to perform visual estimate sampling to assess variability of results between samplers. Training consisted of working through the sampling method by sampling five frames on each of two plots alongside of the principle researcher. Everyone's "eye" was calibrated to that of the principle researcher. The three students then sampled five frames each in eleven plots. An analysis of the running totals of the variance performed on data from 1995 showed that the variance of all variables stabilized at five frames, indicating that five frames were a sufficient sample to account for the within plot heterogeneity of the sample plots. Correlation analysis showed which variables were consistently recorded similarly among all three samplers. Each sampler recorded the length of time taken to sample a plot.

### Results

Sixty-three significant correlations existed between visually estimated variables and measured variables over the two years in the upland (1995 and 1996) and in the valley bottom in 1995 (Table 8). Rill-sheet erosion (estimated) correlated with measured

variables in seven cases in the upland in 1996 and in one case in the valley bottom in 1995. Litter breakdown correlated with measured variables in seven cases across the upland and valley bottom sites. Desirable plants did not correlate with any of the measured variables. Germination sites and utilization correlated with measured variables only one time each over the upland and valley bottom sites. The number of significant correlations ( $p=0.95$ ) for each estimated variable with measured or calculated variables is listed in Table 9.

Results from different samplers were correlated with each other in only seven instances out of a possible 45, or 16 percent of the time (Table 10). The average time to sample native range sites was 27 minutes for five frames. The average time to sample plots in all other upland land uses was 21 minutes for five frames. In comparison, it took an average of three hours to sample plots using the measurement approach, not including time spent on lab processing and data analysis.

Cluster analysis results are shown in Figure 32. Variables were grouped into four categories: pedestalling, rill and sheet erosion, desirable plants; crusting, age distribution, germination sites; litter breakdown, litter abundance, plant spacing; and species diversity, canopy diversity, canopy abundance, that corresponded roughly to the categories, soil stability and water cycling, recovery mechanisms, nutrient cycling and energy flow, suggested by National Research Council 1994.

**Table 8.** Significant correlations between visually estimated and measured variables.

| 1995 valley bottom                     |                       |       | 1995 upland                            |                         |       |
|----------------------------------------|-----------------------|-------|----------------------------------------|-------------------------|-------|
| visual estimate                        | Measured variable     | r     | visual estimate                        | Measured variable       | r     |
| %cover                                 | arthropod taxons      | 0.65  | age class dist.                        | soil phosphorus         | 0.61  |
| %cover                                 | soil total nitrogen   | 0.73  | litter breakdown                       | dead plant biomass      | -0.53 |
| %cover                                 | %soil organic matter  | 0.73  | litter breakdown                       | soil phosphorus         | 0.63  |
| age class dist.                        | soil total nitrogen   | 0.79  | litter breakdown                       | soil NO <sub>3</sub>    | 0.52  |
| age class dist.                        | %soil organic matter  | 0.73  | can. abundance                         | soil potassium          | 0.51  |
| age class dist.                        | live biomass/litter   | 0.63  | can. abundance                         | soil respiration        | 0.57  |
| litter breakdown                       | %organic matter       | 0.86  | can. distribution                      | live plant biomass      | 0.56  |
| litter breakdown                       | plant morph diversity | 0.68  | soil crusting                          | dead plant biomass      | -0.58 |
| litter breakdown                       | %undesirable plants   | 0.63  | soil crusting                          | soil phosphorus         | 0.51  |
| can. abundance                         | soil total nitrogen   | 0.89  | litter abundance                       | infiltration rate       | -0.51 |
| can. abundance                         | %soil organic matter  | 0.83  | pedestalling                           | live plant biomass      | 0.51  |
| can. abundance                         | soil phosphorus       | 0.65  | sp. diversity                          | root biomass            | 0.53  |
| can. abundance                         | %undesirable plants   | 0.64  | sp. diversity                          | plant morph diversity   | 0.55  |
| can. distribution                      | canopy diversity      | 0.72  |                                        |                         |       |
| soil crusting                          | soil total nitrogen   | 0.64  | significance at p=0.95 is r>0.5 (n=15) |                         |       |
| soil crusting                          | %soil organic matter  | 0.66  |                                        |                         |       |
| soil crusting                          | plant morph diversity | 0.70  | 1996 upland                            |                         |       |
| soil crusting                          | %undesirable plants   | 0.68  | visual estimate                        | measured variable       |       |
| germ sites                             | soil total nitrogen   | 0.81  | age class dist.                        | arthropod net sweep     | 0.51  |
| litter abundance                       | canopy diversity      | 0.66  | litter breakdown                       | live/litter             | -0.64 |
| pedestalling                           | soil total nitrogen   | 0.66  | can. distribution                      | %soil organic matter    | 0.63  |
| pedestalling                           | %soil organic matter  | 0.70  | can. distribution                      | plant morph diversity   | 0.54  |
| plant vigor                            | soil total nitrogen   | 0.65  | can. distribution                      | # plant species         | 0.72  |
| plant vigor                            | live biomass/litter   | 0.64  | can. distribution                      | soil carbon/nitrogen    | 0.56  |
| rill-sheet erosion                     | # plant species       | -0.62 | litter abundance                       | # plant species         | -0.62 |
| plant spacing                          | soil phosphorus       | 0.67  | pedestalling                           | dead plant biomass      | 0.55  |
| utilization                            | mammal taxons         | 0.69  | pedestalling                           | litter biomass          | 0.57  |
| significance at p=0.95 is r>0.6 (n=10) |                       |       | plant vigor                            | live plant biomass      | -0.51 |
|                                        |                       |       | plant vigor                            | arthropod net sweep     | 0.53  |
|                                        |                       |       | rill-sheet erosion                     | arthropod taxons        | -0.64 |
|                                        |                       |       | rill-sheet erosion                     | soil total nitrogen     | -0.71 |
|                                        |                       |       | rill-sheet erosion                     | %soil organic matter    | -0.78 |
|                                        |                       |       | rill-sheet erosion                     | plant morph diversity   | -0.65 |
|                                        |                       |       | rill-sheet erosion                     | # plant species         | -0.74 |
|                                        |                       |       | rill-sheet erosion                     | soil NO <sub>3</sub> /N | 0.54  |
|                                        |                       |       | rill-sheet erosion                     | soil carbon/nitrogen    | -0.60 |
|                                        |                       |       | sp. diversity                          | soil total nitrogen     | 0.69  |
|                                        |                       |       | sp. diversity                          | %organic matter         | 0.69  |
|                                        |                       |       | sp. diversity                          | plant morph diversity   | 0.57  |
|                                        |                       |       | plant spacing                          | bulk density            | -0.53 |
|                                        |                       |       | plant spacing                          | soil total nitrogen     | 0.52  |
|                                        |                       |       | significance at p=0.95 is r>0.5 (n=15) |                         |       |

**Table 9.** The number of significant correlations for each visually estimated variable with measured variables is used as an index of usefulness of the estimated variable.

| Variable                | Valley bottom<br>1995 | Upland 1995 | Upland 1996 | Upland<br>total | Grand<br>total |
|-------------------------|-----------------------|-------------|-------------|-----------------|----------------|
| %cover                  | 3                     | 0           | 0           | 0               | 3              |
| pedestalling            | 2                     | 1           | 2           | 3               | 5              |
| rill-sheet erosion      | 1                     | 0           | 7           | 7               | 8              |
| soil crusting           | 4                     | 2           | 0           | 2               | 6              |
| desirable plants        | 0                     | 0           | 0           | 0               | 0              |
| plant age distribution  | 3                     | 1           | 1           | 2               | 5              |
| plant vigor             | 2                     | 0           | 2           | 2               | 4              |
| germination sites       | 1                     | 0           | 0           | 0               | 1              |
| litter breakdown        | 3                     | 3           | 1           | 4               | 7              |
| litter abundance        | 1                     | 1           | 1           | 2               | 3              |
| plant spacing           | 1                     | 0           | 2           | 2               | 3              |
| plant species diversity | 0                     | 2           | 3           | 5               | 5              |
| canopy distribution     | 1                     | 1           | 4           | 5               | 6              |
| canopy abundance        | 4                     | 2           | 0           | 2               | 6              |
| utilization             | 1                     | 0           | 0           | 0               | 1              |

### Discussion

The visual estimates of crusting and pedestalling, in the soil stability category, had significant positive correlations with soil organic matter. Higher concentrations of organic matter are associated with more microbial and fungal activity which can increase soil aggregation and reduce erosion (Eash, et al., 1994).

Estimated litter abundance correlated with measured water infiltration rate. More leaf litter protects soil from crusting and compaction which would allow a faster water infiltration rate.

**Table 10.** Results of correlation analysis between samplers. *r* values greater than 0.50 are significant at  $p=0.95$  and are printed in bold. The headings *a*, *c*, and *j* stand for the different samplers.

|                    |             |          |          |                     |             |             |          |
|--------------------|-------------|----------|----------|---------------------|-------------|-------------|----------|
| % Cover            |             |          |          | Germination sites   |             |             |          |
|                    | <i>a</i>    | <i>c</i> | <i>j</i> |                     | <i>a</i>    | <i>c</i>    | <i>j</i> |
| a                  | 1.000       |          |          | a                   | 1.000       |             |          |
| c                  | .349        | 1.000    |          | c                   | <b>.869</b> | 1.000       |          |
| j                  | .281        | .349     | 1.000    | j                   | <b>.643</b> | .429        | 1.000    |
| Pedestalling       |             |          |          | Litter breakdown    |             |             |          |
|                    | <i>a</i>    | <i>c</i> | <i>j</i> |                     | <i>a</i>    | <i>c</i>    | <i>j</i> |
| a                  | 1.000       |          |          | a                   | 1.000       |             |          |
| c                  | -.260       | 1.000    |          | c                   | .416        | 1.000       |          |
| j                  | .023        | -.100    | 1.000    | j                   | .184        | .502        | 1.000    |
| Rill/sheet erosion |             |          |          | Litter abundance    |             |             |          |
|                    | <i>a</i>    | <i>c</i> | <i>j</i> |                     | <i>a</i>    | <i>c</i>    | <i>j</i> |
| a                  | 1.000       |          |          | a                   | 1.000       |             |          |
| c                  | -.270       | 1.000    |          | c                   | <b>.704</b> | 1.000       |          |
| j                  | .373        | -.333    | 1.000    | j                   | .244        | .348        | 1.000    |
| Soil crusting      |             |          |          | Plant spacing       |             |             |          |
|                    | <i>a</i>    | <i>c</i> | <i>j</i> |                     | <i>a</i>    | <i>c</i>    | <i>j</i> |
| a                  | 1.000       |          |          | a                   | 1.000       |             |          |
| c                  | .504        | 1.000    |          | c                   | .566        | 1.000       |          |
| j                  | <b>.670</b> | .393     | 1.000    | j                   | .510        | .542        | 1.000    |
| Desireable plants  |             |          |          | Species diversity   |             |             |          |
|                    | <i>a</i>    | <i>c</i> | <i>j</i> |                     | <i>a</i>    | <i>c</i>    | <i>j</i> |
| a                  | 1.000       |          |          | a                   | 1.000       |             |          |
| c                  | .121        | 1.000    |          | c                   | .550        | 1.000       |          |
| j                  | .448        | .109     | 1.000    | j                   | <b>.618</b> | <b>.712</b> | 1.000    |
| Age class dist.    |             |          |          | Canopy distribution |             |             |          |
|                    | <i>a</i>    | <i>c</i> | <i>j</i> |                     | <i>a</i>    | <i>c</i>    | <i>j</i> |
| a                  | 1.000       |          |          | a                   | 1.000       |             |          |
| c                  | .166        | 1.000    |          | c                   | .185        | 1.000       |          |
| j                  | <b>.848</b> | -.136    | 1.000    | j                   | .344        | .412        | 1.000    |
| Plant vigor        |             |          |          | Canopy abundance    |             |             |          |
|                    | <i>a</i>    | <i>c</i> | <i>j</i> |                     | <i>a</i>    | <i>c</i>    | <i>j</i> |
| a                  | 1.000       |          |          | a                   | 1.000       |             |          |
| c                  | .074        | 1.000    |          | c                   | .349        | 1.000       |          |
| j                  | -.179       | .344     | 1.000    | j                   | .090        | <b>.667</b> | 1.000    |
|                    |             |          |          | Utilization         |             |             |          |
|                    |             |          |          |                     | <i>a</i>    | <i>c</i>    | <i>j</i> |
|                    |             |          |          | a                   | 1.000       |             |          |
|                    |             |          |          | c                   | .528        | 1.000       |          |
|                    |             |          |          | j                   | -.308       | -.164       | 1.000    |

Percent chaining = 32.00

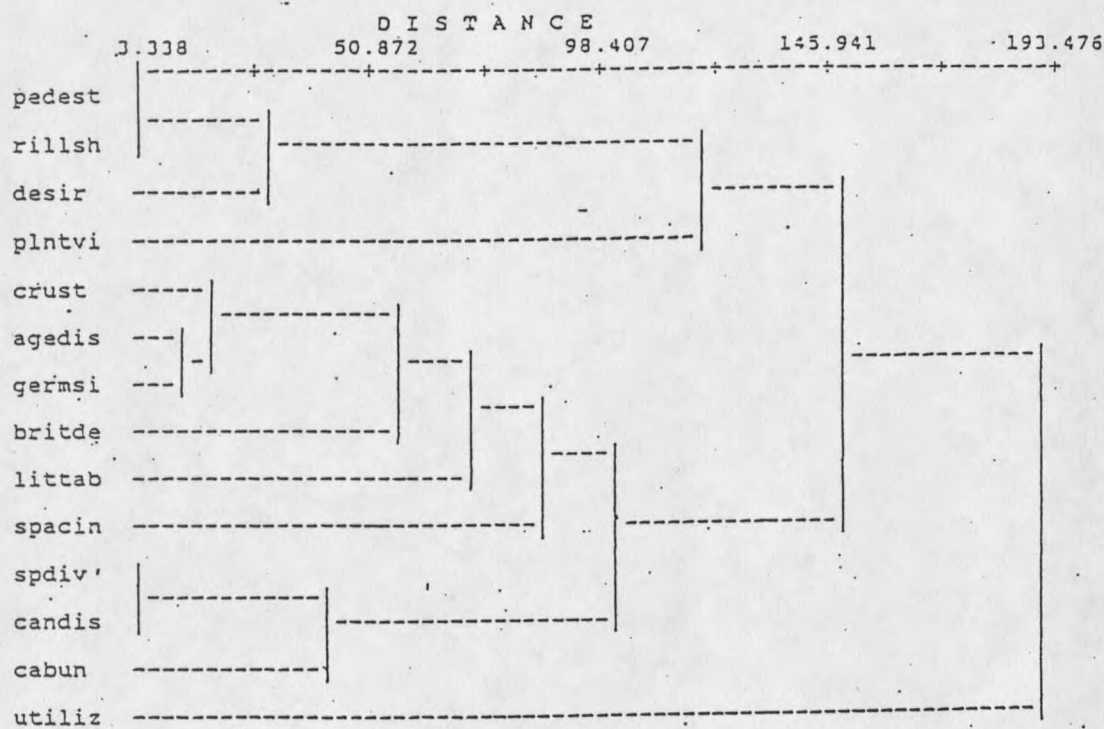


**Figure 32.** Cluster analysis using the Euclidean distance, nearest neighbor approach, for the visually estimated variables. Abbreviations: pedest = pedestalling; rillsh = rill and sheet erosion; desir = desireable plants; plntvi = plant vigor; crust = soil crusting; agedis = plant age distribution; germsi = germination sites; britde = litter breakdown; littab = litter abundance; spacin = plant spacing; spdiv = plant species diversity; candis = canopy distribution; cabun = canopy abundance; utiliz = utilization.

The visual estimate, desirable plants, did not correlate with any of the measured variables. The presence of undesirable plants (weeds) can have different ecological interpretations. Perhaps many weeds could be a sign of a recovering ecosystem which may imply high resiliency. Land with a low percentage of weeds may be ecologically intact and functioning with all niches filled by native species or it may be subjected to agricultural practices (herbicides) that, while eliminating undesirable plant species, also reduce total species diversity and, therefore, rangeland health.

Monitoring the same land over time without a desired landscape goal is simply keeping track of environmental variation over time. Weaver and Forcella (1979) showed that soil nutrient levels vary over time. Our study showed significant correlations between variables measuring soil nutrients, such as total nitrogen, phosphorous, and potassium, with the visually estimated variables of percent cover, plant age distribution, plant canopy abundance, plant vigor, and plant spacing. It follows that these visual estimates also vary with time. Therefore, to interpret the monitoring results for the purpose of land management, a reference site or landscape goal is necessary to compare with monitored plots. Interpretation of monitoring results over time could be in terms of similarity to the reference site, or as a trend either towards or away from the desired landscape goal.

The number of significant correlations between visually estimated and measured variables could be considered an index of the usefulness of each estimated variable. Using this reasoning, rill and sheet erosion, litter breakdown, soil crusting, and canopy distribution were the most useful estimates. Percent undesirable plants, utilization, and

germination sites, were the least useful estimates. However, only four visually estimated variables, age class distribution, litter breakdown, litter abundance, and pedestalling had significant correlations with measured variables in both the 1995 and 1996 upland samples and in the 1995 valley bottom samples (Table 8). This finding shows the value of using multiple indicator variables to characterize ecosystem function (water cycling and soil stability, recovery mechanisms, and nutrient cycling and energy flow) when sampling in different environments and when sampling over time. If one visual estimate does not characterize ecosystem function, then perhaps another one will. The preponderance of evidence approach proposed by National Research Council (1994) appears to be supported by this finding.

The samplers, who had minimal training and calibration of their visual estimation skills with one another, reported different results when sampling over the same area. The incidence of significant correlation between samplers was low (16 percent). This finding appears to limit the usefulness of the sampling method. If sampling is to be performed at the same site over time, the same person should do the sampling. If sampling is to be over a wide area, results would not be comparable unless the same person was doing the sampling. Alternatively, more extensive training of samplers could occur than was employed in this study. A full day of training should be sufficient to calibrate multiple samplers with each other.

Cluster analysis results showed four groups of variables instead of the three proposed by National Research Council, 1994. Soil crusting, germination sites and age distribution were grouped in a possible recovery mechanisms category. Desirable plants and plant

vigor are grouped with pedestalling and rill and sheet erosion in a possible soil stability category. Loss of topsoil due to erosion could affect plant vigor and facilitate the establishment of weed species so this grouping makes sense. Nutrient cycling and energy flow measures separated out into two distinct groupings: litter breakdown, plant spacing, and litter abundance in a nutrient cycling category, and species diversity, canopy distribution, and live canopy abundance in an energy flow category. The similarity of the cluster analysis groupings to the National Research Council's (1994) lends support to this approach to organizing rangeland health indicators.

### **Conclusions**

Visual estimates of rangeland health indicator variables correlated with measured indicator variables in both valley bottom and upland areas. Monitoring by visual estimates of vegetation and soil surface condition took considerably less time than did actual measurements. The following considerations should be observed in order for a monitoring program, employing this or similar monitoring methods, to be successful: 1) Multiple variables are necessary to characterize ecosystem function when sampling across different locations and at different times. 2) Have a desired landscape condition goal, and monitor over time in the same location. Variable scores can be interpreted by noticing a trend either towards or away from the landscape goal. 3) Results can be compared to a base reference site that is sampled during the same year and season, as the monitored plot. Results can be instantly interpreted by comparing differences between the monitored plot and the reference site. 4) A pilot study is necessary to determine the number of frames

necessary to adequately characterize a site. An analysis of the running totals of the variance would show how many frames it is necessary to sample for a given ecosystem type. 5) When a monitoring program is to involve comparisons of measurements between different samplers, adequate training should be undertaken to calibrate multiple samplers to each other.

### Chapter 3

## THE RELATIONSHIP BETWEEN NET RADIATION AND ECOSYSTEM STRUCTURE ACROSS EIGHT DIFFERENT LAND USES

### Introduction

In experimentally controlled, thermodynamically open systems, structures form that dissipate imposed energy gradients (Schneider and Kay 1994). The entropy of the larger global system increases despite the increase in order (structure) within the immediate system, thus satisfying the second law of thermodynamics (Schneider and Kay, 1994). Convection currents in a liquid with a heat gradient imposed on it are examples of spontaneous structures forming to dissipate energy. Kay and Schneider, (1992) hypothesized that this principle holds true in all scales of systems including ecosystems.

Several studies have measured the relationship between ecosystem structure and entropy. Luvall and Holbo (1989) found a relationship between forest canopy successional stage and the percentage of incoming solar radiation degraded into non-radiative processes. Akbari (1995) found a positive relationship between the plant canopy temperature air temperature differential, and calories per gram of plant material in measured grassland plots. Schneider and Kay (1994) analyzed carbon flow data from the Crystal River in Florida (Homer and Kemp, 1975) and found that a "stressed" ecosystem

with fewer food web cycles had less energy throughput than the "unstressed" system.

Therefore it is plausible that energy dissipation by an ecosystem may be a good measure of ecosystem structure or integrity.

This study attempted to use net radiation to compare energy dissipation with different measures of ecosystem structure. The intent was to compare the effectiveness of different agricultural ecosystems at dissipating incoming solar energy. The study included two measures of ecosystem structure: volume of vegetation per square meter, and an index of ecosystem integrity composed of fourteen soil and vegetation variables. Net radiation above the plant canopy served as a measure of energy dissipation.

Net radiation, the difference between incoming solar radiation and outgoing radiation from a terrestrial ecosystem is the energy available for work (Barbour et al., 1980). It follows that higher net radiation measured means more energy is being processed by organisms in the ecosystem.

The first objective was to determine the variation in net radiation measured over the growing season and then derive a single integrated value to test the following hypotheses: Hypothesis one was that net radiation would be positively correlated with the volume (height x estimated area) of the plant canopy in each of the different agroecosystems studied. Hypothesis two was that total net radiation, integrated over the study period, would be positively correlated with an ecosystem integrity index.

### **Materials and Methods**

The locations of the study sites were within two miles of each other, North of the town of Three Forks, Montana,  $45^{\circ} 55' N$   $111^{\circ} 36' W$ . Elevation was 1301.5 m above sea

level. Soils were silt loams derived from loess parent material. The study area received an average of 30 cm of precipitation per year. Sampling occurred on four dates during the summer of 1996, June 7, July 26, August 22, and September 29. Eight different land uses were included in the study; native shrub range, dominated by blue gramma (*Boutaloua gracilis*), and sagebrush (*Artemesia tridentata*) vegetation; Conservation Reserve Program land planted to a mixture of crested wheat grass (*Agropyron cristatum*) and alfalfa (*Medicago sativa*); a dryland hay field planted with a mixture of Russian wild rye (*Elymus giganteus*) and *Agropyron cristatum*; a center pivot irrigated wheat field; a center pivot irrigated alfalfa field; a dryland wheat field; a fallow field; and a gravel parking lot outside a local flour mill. All sites had a level aspect.

Irrigation schedules for the two center pivot sites were not known. However, we assumed that irrigation was scheduled to minimize plant water stress. The alfalfa field was cut between the first and second sampling dates and between the third and fourth sampling date. The irrigated wheat field was harvested and the stubble plowed between the third and fourth sampling date. The dryland wheat field was harvested between the second and third sampling date. There was a cutting on the dryland hay field between the first and second sampling date.

All net radiation measurements occurred between 10:30 am and 2:30 p.m. on cloudless days. Sampling occurred at all sites each day except for June 7 when afternoon clouds made it necessary to sample the shrub range on June 10. Sampling order varied each day. All sampling dates had clear cloudless skies. The intention of this sampling

scheme was to eliminate any variation in atmospheric emissivity and incoming solar radiation.

Net radiation was measured with a Radiation Energy Balance Systems Q6 model net radiometer which sat on a tripod one meter above the plant canopy. Placement of the tripod occurred in a location representative of the land use being measured. For example in the fallow site, placement of the net radiometer was located over bare soil with no weeds. In the wheat alfalfa, hay, CRP and shrub range sites placement was above healthy thick canopy. Sites were not resampled in the same place to avoid sampling in a disturbed spot. The boom of the instrument extended facing south to eliminate shadows. The net radiometer equilibrated for three minutes before reading a volt meter output in tenths of a millivolt.

Luvall and Holbo (1989) looked at the proportion of incoming radiation to outgoing radiation from the plant canopy. Our instrument measured the difference between incoming and outgoing radiation. While these two measures differ, it was assumed that under positive flux conditions, the same order of plot ranking would occur using net radiation as would occur using out-going divided by incoming radiation.

The wind speed correction factor, supplied by the manufacturer of the net radiometer, was not applied to the net radiation readings. In order for wind to affect net radiometer readings, the internal temperature of the instrument must be greater than the surrounding air temperature. Conductive heat loss, increased by wind speed, would lower the apparent incoming and reflected radiation sensed by the net radiometer. In my experiment, the instrument stood outside at each site for less than fifteen minutes, then

was packed away and transported to the next site. The net radiometer box inside the van was cooler than the air temperature outside, so it was assumed that the net radiometer was always cooler than the air temperature. Therefore, no wind speed correction factor was used.

Environmental conditions and energy transfer processes that are not necessarily related to ecosystem structure may affect net radiation measured above the plant canopy. To accurately distinguish between the effects of ecosystem structure and environmental conditions present during sampling would require that additional environmental data be collected along with net radiation measurements. A thorough understanding of energy transfer in ecosystems and the use of a computer model such as Cupid (Norman, 1986) would be necessary to analyze the energy transfer occurring in the study sites. Such analysis is beyond the scope of this study. However, the following environmental measurements were taken, with each net radiation measurement, in the event that analysis could be conducted at some future date:

*Wind Speed.* A hand held digital anemometer measured wind speed in tenths of meters per second. Readings were at shoulder height, approximately 140 cm off the ground, taken simultaneously with reading the voltmeter output from the net radiometer.

*Time.* Recorded time of day was simultaneous with the net radiometer reading.

*Relative Humidity.* Wet and dry bulb thermometer readings from an Assmann psychrometer held at shoulder height (140 cm) provided temperature readings for determining relative humidity from psychrometric tables (Torok, 1935).

*Soil Temperature.* A hand held infrared thermometer, set for an emissivity of 95, was aimed at the soil surface under the plant canopy under the net radiometer sensor and the digital readout in tenths of degrees C was recorded.

*Air Temperature.* The hand held infrared thermometer, with the emissivity set at 95, was held at arms length 140 cm above the ground pointing directly away from the sun and the temperature read from the instrument.

*Soil Moisture Content.* A hand trowel was used to take a sample from the top five cm of the soil. The sample was placed in a lined soil sample bag, transported to the laboratory, weighed, dried in a soil drying oven at 65°C re-weighed, and the soil moisture content calculated as a percentage of the dry weight of soil.

*Height of Vegetation.* Height of the top of the plant canopy was measured directly under the sensor of the net radiometer.

*Plant Canopy Cover.* Percent plant cover was estimated in a 0.5 m<sup>2</sup> sampling frame placed under the sensor of the net radiometer. Vegetation height multiplied by percent canopy cover determined volume of vegetation.

All measurements were taken twice at each plot at locations separated by approximately eight meters. Soil moisture content was sampled only once in each plot at a point midway between the two locations of the net radiometer tripod.

To calculate the ecosystem integrity index for a plot, the following methods were used: At each land use site a 150-meter baseline was established and transects were positioned at 50, 100, and 150 meters. Six, 0.5 m<sup>2</sup> sampling frames were placed randomly along each cross transect. All plots were sampled during June 1996. A pilot study

determined that 18 samples (frames) were required to stabilize the variance in most of the following measurements.

*Plant Species Composition:* Within each sampling frame, all plants were identified to species, and the percent cover by species was noted. For each species the life form, either annual forb, annual grass, perennial forb, perennial grass, biennial forb, perennial shrub, or tree was noted. The Shannon Weiner diversity index (Goldsmith, et al, 1986) was used to create a morphological diversity index. Plant species richness was the number of species observed in the sample site inside and outside of the sample frames of the sample frames during the course of sampling the entire suite of measurements.

*Ground Cover:* Visual estimates were made for the following categories, bare soil, moss, litter, and plant canopy cover. The percent of the sampling frame area was measured by visual estimate. All percent cover measures had the potential to reach 100%. Above ground vegetation structure was characterized as the percent canopy cover in three height classes: 0-0.5 m, 0.5-2.0 m and >2.0 m (Jensen, 1992). Plant canopy diversity was calculated using the Shannon Weiner diversity index (Goldsmith, et al, 1986).

*Root Biomass:* Five, systematically located soil cores of 10 cm depth and 2 cm diameter, were taken within nine 0.5 m<sup>2</sup> sample frames to estimate root biomass. (Milchunas and Lauenroth, 1989, Bartos and Sims, 1974, Coffin and Lauenroth, 1991). Once per week the root core samples were washed, sieved in a # 35 soil sieve, and set to dry in a 40.5° C drying oven for 48 hours then weighed. Results were expressed in grams of roots per m<sup>2</sup> in the top ten cm of soil.

*Soil Bulk Density:* A 10 cm deep, 5 cm diameter soil core was extracted and placed in a sealed soil sample bag. Soil cores were taken adjacent to nine vegetation sample frames. Each soil core was taken back to the laboratory, dried for 72 hours, at 65° C and weighed. Bulk density was calculated as grams per cm<sup>3</sup>.

*Water Infiltration Rate:* was measured by pounding a 16 cm diameter PVC ring 5 cm into the ground adjacent to nine sampling frames. The infiltration of 5 cm of water poured into the ring was timed. If infiltration time exceeded sixty minutes, the time was recorded as sixty-five minutes.

*Soil Nutrient Analysis:* Soil samples from the bulk density cores were pooled from all nine cores sampled in a plot and analyzed for soil organic matter, total Kjeldahl nitrogen, and nitrate in the Montana State University Soil Analytical Lab. A soil carbon to nitrogen ratio and a soil nitrate to nitrogen ratio were calculated as components of the ecosystem integrity index.

The ecosystem integrity index was determined by comparing each variable measurement to values obtained by measuring a base reference area. The base reference site was a field plot, near the study area, that scored closest, out of thirty field sites, to a subjective optimum for each of the variables measured. Values were scaled, the measurements for each plot were divided by the base reference value, and the results for all variables were averaged to obtain the ecosystem integrity index. See Chapter One for complete details of the development of the ecosystem integrity index.

Due to the inherent differences between land uses, and resultant impacts on plant canopy volume, it was not appropriate to conduct correlation analysis on plant canopy

volume *versus* net radiation across land use types. Correlation analysis was conducted for each land use site to test the hypothesis that there was a relationship between plant canopy volume and net radiation within each type.

To determine average net radiation over the study period, net radiation values at each land use site were plotted over time. The area under the curve of the line connecting the four net radiation values sampled for each land use site was calculated to determine the integrated total net radiation for the season. This value was divided by the number of days between the first and last sample date to give the average integral of net radiation for the season.

Hypothesis two was tested by calculating correlation coefficients and determining significance of the relationship between average net radiation and the ecosystem integrity index (Steel and Torrie, 1980).

### **Results**

Net radiation at each site was plotted against sampling date during the summer of 1996. There was a general negative trend for all sites (Figure 33). This general decrease in net radiation may have been due to the drying out of the soil over the course of the summer, accompanied by the maturing and senescing of the vegetation. The rate of change in net radiation was lowest in the two non-vegetated sites, fallow field and parking lot. It is plausible that a positive slope to the net radiation curves would have been present in the early season as the green up of vegetation occurred. Sampling earlier in the season may have identified this response.

The range site ranked highest in net radiation on the final sample date, September 29 (Figure 33). A possible interpretation is that some plants in the species rich (32 plant species) native system were still actively processing incoming solar energy after the species poor (maximum seven plant species) altered ecosystems had shut down in the later stages of the growth season.

When correlation analysis was run on plant canopy volume *versus* net radiation, the correlation coefficients were lowest for the range site ( $r=0.16$ ), and CRP ( $r=0.26$ ) plots. These results were expected because these sites experienced no harvesting so the variation in plant canopy volume was less over the course of the season. Therefore, other factors may have been explaining more of the variation in net radiation. The dryland hay site had the highest correlation ( $r=0.574$ ). In no site was the relationship between plant canopy volume and net radiation significant ( $p<0.05$ ) (Table 11).

**Table 11.** Correlation coefficients ( $r$ ) between net radiation and plant canopy volume. Soil  $\text{NO}_3$  and average moisture levels are listed for comparison.

| Plot              | $r$  | Soil $\text{NO}_3$<br>ppm | Soil moisture<br>percentage |
|-------------------|------|---------------------------|-----------------------------|
| Native range      | .155 | 0.5                       | 1.3                         |
| CRP               | .260 | 5.4                       | 1.1                         |
| Irrigated wheat   | .433 | 25.2                      | 2.5                         |
| Dryland wheat     | .466 | 32.2                      | 5.1                         |
| Irrigated alfalfa | .563 | 33.7                      | 8.0                         |
| Non-irr. hay      | .574 | 2.9                       | 2.0                         |

Other factors besides plant canopy volume were involved in explaining radiation capture in addition to plant canopy volume. If net radiation is considered to be a measure of the amount of the sunlight resource that is being used, then a perfect

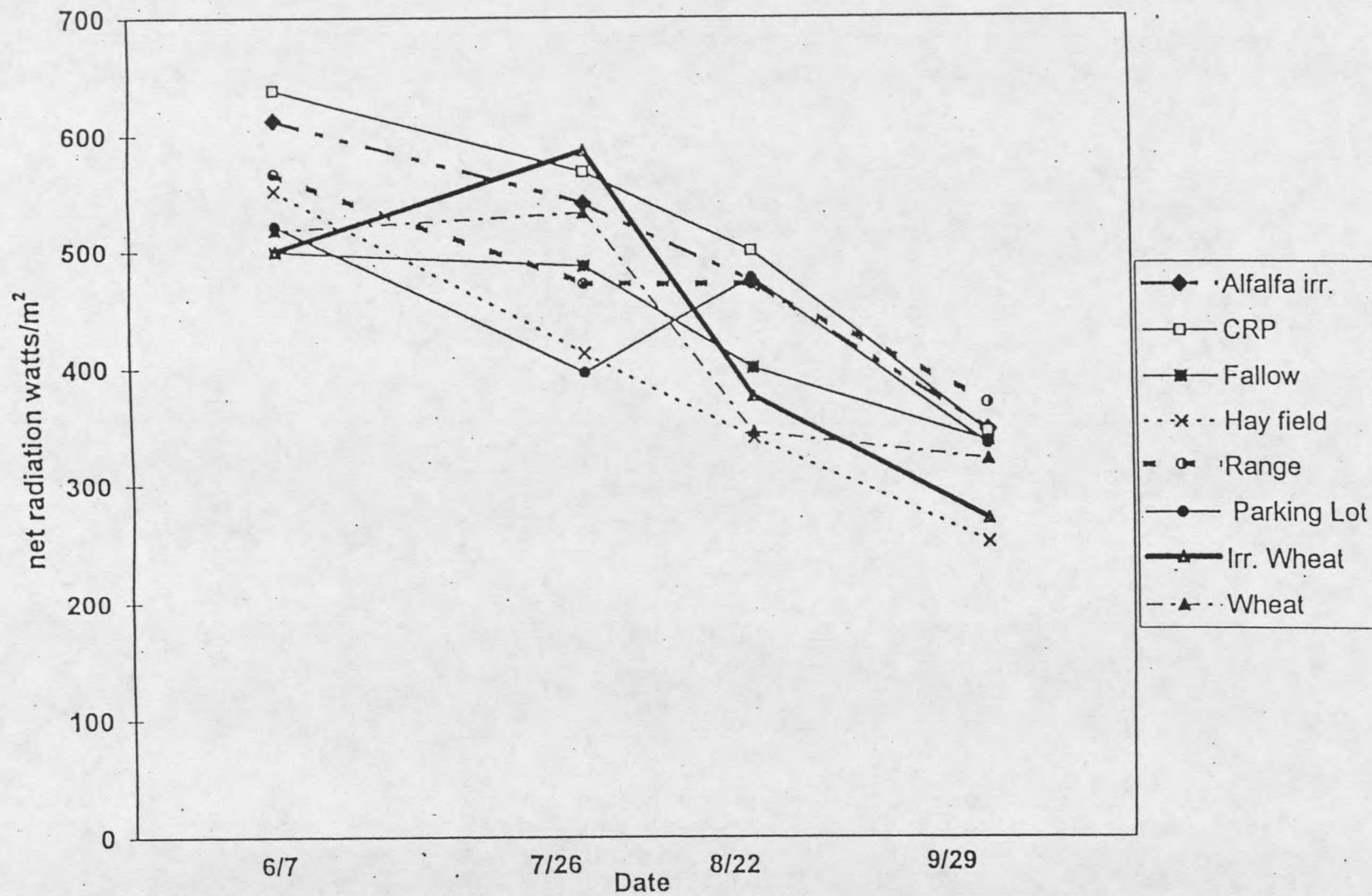


Figure 33. Net radiation plotted for all land use sites for all dates.

correlation between volume of vegetation and net radiation would occur only when sunlight was the limiting resource. In the semi desert environment of Three Forks, MT we can assume that sunlight was close to a limitless resource. Thus, the correlation should have improved as potential limiting resources such as plant available nitrogen ( $\text{NO}_3$ ) and water, were added to the systems. This result was observed in the data. As  $\text{NO}_3$  concentration in the soil increased so did the correlation coefficient. A similar trend was observed when the average soil moisture content of each site was compared to the correlation coefficients (Table 11). The exception was the hay site. Some other factor, possibly a high albedo due to light colored straw on the soil surface, was influencing net radiation measured.

Ranking of sites by net radiation integrated over the four sampling dates is presented in Table 12. CRP (527.2 watts/ $\text{m}^2$ /day) and alfalfa (505.3 watts/ $\text{m}^2$ /day) ranked highest. Surprisingly, the hay site (395.1 watts/ $\text{m}^2$ /day) ranked lowest, even below the fallow and parking lot land use sites. The light color and therefore high albedo of this site, due to dry straw on the soil surface, could have lowered net radiation measurements.

The ecosystem integrity index was not significantly correlated ( $r=0.11$ ,  $p<0.05$ ) with net radiation averaged over the four sampling dates. A stronger relationship might be expected between ecosystem integrity and total growing season net radiation if multiple plots within the same land use were sampled. Each land use site had different management practices and plant species composition which would determine which energy transfer processes and environmental factors were most important in affecting net radiation. Table 13 shows that different environmental factors were correlated with net

radiation at each different land use site. At the fallow site, air temperature was significantly correlated ( $r=0.93$  at  $p<0.05$ ) with net radiation. At the dryland hay site, relative humidity ( $r=0.99$ ) was significant; at the parking lot site, soil temperature was significant ( $r=0.91$ ); at the wheat site, relative humidity ( $r=0.94$ ) and soil temperature ( $r=0.97$ ) were significant.

**Table 12.** Ranking net radiation values averaged over June 7 through September 29, and the associated ecosystem integrity index scores.

| Land use type     | Avg. net radiation        | Ecosystem integrity |
|-------------------|---------------------------|---------------------|
|                   | watts/m <sup>2</sup> /day | index score 0-1     |
| CRP               | 527.2                     | 0.60                |
| Irrigated alfalfa | 505.3                     | 0.42                |
| Native range      | 461.4                     | 0.68                |
| Irrigated wheat   | 455.4                     | 0.48                |
| Wheat             | 441.2                     | 0.42                |
| Fallow field      | 439.9                     | 0.46                |
| Parking lot       | 436.0                     | 0.24                |
| Non-irr. hay      | 395.1                     | 0.61                |

**Table 13.** Correlation coefficients ( $r$ ) between net radiation and environmental variables measured at each site. Significant correlations at  $p=0.05$  were values  $>0.90$  with  $n=4$ .

|                       | Irrigated alfalfa | CRP   | Fallow field | Non irrigated hay | Native range | Parking lot | Irrigated wheat | Non-irrigated wheat |
|-----------------------|-------------------|-------|--------------|-------------------|--------------|-------------|-----------------|---------------------|
| date                  | -0.98             | -0.97 | -0.93        | -0.98             | -0.97        | -0.80       | -0.77           | -0.85               |
| air temp.             | 0.66              | 0.50  | 0.93         | 0.79              | -0.58        | -0.22       | 0.68            | 0.38                |
| wind speed            | 0.42              | -0.84 | -0.84        | -0.62             | -0.56        | -0.65       | 0.48            | -0.62               |
| rel. humidity         | 0.73              | 0.63  | 0.86         | 0.99              | 0.86         | 0.27        | 0.58            | 0.94                |
| soil temp.            | 0.79              | 0.24  | 0.68         | 0.87              | 0.63         | 0.91        | -0.72           | 0.97                |
| time                  | 0.32              | -0.17 | -0.54        | 0.39              | -0.83        | -0.51       | 0.45            | -0.67               |
| veg. ht.              | 0.60              | -0.57 | -            | 0.83              | 0.13         | -           | 0.56            | 0.52                |
| soil H <sub>2</sub> O | -0.49             | -0.63 | -0.69        | -0.53             | -0.18        | 0.76        | 0.67            | -0.74               |
| %Cover                | 0.19              | 0.36  | -            | -0.54             | 0.27         | -           | 0.29            | 0.27                |
| veg volume            | 0.56              | 0.26  | -            | 0.44              | 0.15         | -           | 0.43            | 0.47                |

At all land use sites there was a high correlation between net radiation and sampling date. Sampling date was not consistently correlated with other measures. Therefore, it is plausible that incoming solar radiation, which changed over the season, may be significantly correlated with sampling date (Table 13).

### Discussion

If a study is to determine which land uses are the most effective in utilizing incoming solar energy, sampling should begin as soon as the snow melts, in March, and continue until the snow covers the ground in the fall. Sampling in this way would more accurately reflect the presence of early and late season plants in rangeland plots, which may be photosynthesizing, and transpiring while cropped fields are still bare.

To adequately assess, with statistical robustness, whether or not there is a relationship between ecosystem structure and dissipation of incoming solar energy, a different experimental design should be used. First, to measure net radiation, a total hemispherical net radiometer, along with a pyronometer should be used. With these two instruments it would be possible to separate out measurements of incoming and reflected long wave radiation, incoming and reflected short wave radiation, net short wave radiation (albedo) net long wave radiation, and total net radiation. From these measurements the proportion of total net radiation attributed to albedo could be calculated. The proportion of the total incoming solar radiation that was dissipated by the system could also be calculated.

An ideal setting for testing the hypothesis that an ecosystem with more structure degrades a higher proportion of incoming solar energy, would be in a site such as

the LTER site at Cedar Creek, MN (Tilman et al., 1996). Multiple experimental grassland field plots of varying species richness are present in close proximity to each other at this site. An example experimental design would be to have five repetitions of plots with five different levels of species richness and varying species composition. Different measures of ecosystem structure such as plant morphological diversity, and plant species richness as well as plant canopy volume and an ecosystem integrity index could be treated as a continuum and compared across the different biodiversity treatments. We found that two measurements at eight plots took enough time (an average of 20 minutes with driving, loading and unloading of sampling equipment) that it was just barely possible to sample eight plots during the middle of the day when incoming solar radiation is presumed not to vary. If environmental measurements (relative humidity, air temperature, wind speed, soil temperature, time, and soil moisture content) were not taken, or more field assistants were involved in the study, sampling time would be reduced.

### Summary

There was a general negative trend in net radiation from June 7 to September 29 at all land use sites. This result implied that sampling should have commenced earlier in the season. There was no significant relationship ( $p < 0.05$ ) using correlation analysis, between net radiation and plant canopy volume at any site. The CRP and alfalfa land use sites had the highest total net radiation measurements, integrated over the length of the study. The dryland hayfield had the lowest integrated net radiation. There was no significant correlation ( $p < 0.05$ ) between net radiation averaged over the season and the ecosystem integrity index.

## **Chapter 4**

# **THE RELATIONSHIP BETWEEN MUNSELL SOIL COLOR VALUE AND SOIL ORGANIC MATTER AT A LAND FORM SCALE**

## **Introduction**

Soil organic matter content is a measure included in virtually every data set used to assess soil health (Doran and Parkin, 1994; Larson and Pierce, 1994; Karlen and Stott, 1994; Garlynd et al., 1994; National Soil Survey Center, 1996). Typically percent soil organic matter is assessed by laboratory analysis. Zelenak (1995) has shown that a strong relationship existed between Munsell soil color value and percent soil organic matter at the field scale ( $r^2 = .90$ ). When soil samples were stratified by vegetation cover and salt content, regression models using soil color and other easily measured climate variables were able to explain about 50 percent of the variation in organic matter across the state of Montana (Zelenak, 1995). The objective of this study was to determine if a relationship existed between soil organic matter and Munsell color value at the landform scale. A quick and easy method to assess soil organic matter variation across different land uses on the same landform would help in comparing the effects of land use on soil health. Lower sampling cost allows for more samples and greater statistical reliability.

Numerous studies have been done examining the ability of people to accurately assess soil color. Agreement among observers ranged from 60 to 95 percent (Post, et al., 1993, Cooper, 1990, Shields et al., 1966, Pomeroy and Knox, 1962).

Zelenak (1995) thoroughly investigated and described the relationship between soil organic matter content and soil color. A color chart for determining percent organic matter in Illinois was developed by Alexander (1969). Page (1974) found a high correlation ( $r^2=0.89$ ) between color and soil organic matter in the Coastal Plain region of South Carolina. Franzmeier (1988) developed relationships between soil organic matter and Munsell color value for Indiana soils after stratifying by soil texture and drainage.

We tested the hypothesis that Munsell soil color value can predict soil organic matter across varied land uses within the same landform.

### **Materials and Methods**

Sampling occurred during June and July of 1995 and 1996. The study site was a twenty-five square mile area surrounding Three Forks, Montana. We stratified the study site into two landforms, upland and 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. The following are general descriptions of the vegetation and land uses of the sample plots. The upland native range plots were dominated by blue gramma (*Bouteloua gracilis*), and sagebrush (*Artemisia tridentata*). In 1986 the Conservation Reserve Program (CRP) went

sagebrush (*Artemesia tridentata*). In 1986 the Conservation Reserve Program (CRP) went into effect, converting wheat fields to perennial grasslands. Plots in CRP were mostly planted to crested wheatgrass (*Agropyron cristatum*) or a mixture of crested wheatgrass and alfalfa (*Medicago sativa*). In 1996 some CRP land was taken out of the government program and grazed. Plots in former CRP lands were classified for purposes of this study, as seeded range. One seeded range plot was sampled in 1995 and was in a pasture planted to Russian wild rye (*Elymus giganteus*). One upland dryland hay field plot was in a field of mixed native species, alfalfa (*Medicago sativa*) and crested wheatgrass, (*Agropyron cristatum*) the other hay field plot was in a field planted with a mixture of Russian wild rye (*Elymus giganteus*) and crested wheatgrass (*Agropyron cristatum*). The irrigated wheat plot was in a center pivot irrigated field. The wheat and fallow plots were in fields with yearly rotation.

The historic use of the valley bottom sites has been cattle pasture. Forested riparian plots were in cottonwood (*Populus angustifolia*) groves along the Jefferson River. Non forested riparian plots dominated by Kentucky bluegrass (*Poa pratensis*), foxtail barley (*Hordeum jubatum*), and Baltic rush (*Juncus balticus*) were in low lying grassland areas subject to periodic flooding. Highway roadside plots alongside Interstate Highway 90 were planted with crested wheatgrass (*Agropyron cristatum*). The ungrazed plot was in the infield of the local airport that has been fenced off for at least the last 30 years. Grazed valley bottom range plots were in fields dominated by blue gramma (*Bouteloua gracilis*) and Western wheatgrass (*Agropyron smithii*). Residential plots were

sampled in the lawns in front of houses in the town of Three Forks. Vegetation was mostly Kentucky blue grass (*Poa pratensis*), and quack grass (*Agropyron repens*).

The study area was divided into a grid of 47 by 48 cells of approximately 6.4 acres in size. Each cell (plot) was assigned a land use and soil samples were taken from the predominant land use in the 6.4 acre plot. We sampled thirty-nine plots in the upland and seventeen plots in the valley bottom. Sampling was conducted to cover the entire range of land uses and to give broad spatial coverage to both the valley bottom and upland study areas. At each sample plot a 150 meter baseline transect traversed the major cover type represented in the cell. Sampling transects crossed the baseline at 50, 100, and 150 meters. Nine soil cores were taken randomly along the three cross transects. Sample cores were ten cm deep, and five cm in diameter. We placed samples in sealed bags, took them to the lab, and dried them. At the end of the sampling season, samples were ground for thirty seconds in a mechanical soil grinder, pooled by plot, mixed and analyzed for soil organic matter at the Montana State University Soil Analytical Lab.

We assessed soil color value in the laboratory under florescent lighting. Samples were separated by landform into either upland or valley bottom. Thirty-nine upland samples and 17 valley bottom samples were matched to Munsell color chips, interpolating between chips as suggested by Zelenak (1995). Soil value and chroma were determined for each sample under both dry and moist conditions.

The method suggested by Shulze et al (1993) and tested by Zelenak (1995) was used to develop the model for predicting soil organic matter based upon color. We selected six soil samples from each land form group, representing the full range of Munsell color

values present (Tables 14 and 15). We then created a linear regression model for both moist and dry color values verses percent organic matter for the upland and valley bottom. The regression analyses yielded four models that were tested with independent data sets consisting of the 33 remaining samples from upland plots and 10 remaining samples from valley bottom plots to determine their predictive capability.

### Results

Table 16 summarizes the results of linear regression analyses of moist and dry Munsell color values verses soil organic matter for the Three Forks valley bottom. The linear regression model for valley bottom dry color values is:

$$OM = -1.2916 * \text{dry value} + 12.856$$

The linear regression model for valley bottom moist color values is:

$$OM = -2.3389 * \text{moist value} + 14.148$$

Using moist color value produced a better fit of the linear regression model to the data than dry values, adjusted  $r^2 = 0.55$  for moist value verses adjusted  $r^2 = 0.35$  for the dry value (Figures 34 and 35).

Table 17 summarizes the results of linear regression analyses of moist and dry Munsell color values verses soil organic matter for the upland landform. The linear regression model for upland dry color values is:

$$OM = -0.3539 * \text{dry value} + 3.4772$$

**Table 14.** Color value and organic matter content of the six samples composing the color spectrum of valley bottom soil samples used in making the regression model.

| Plot | Land use              | Organic matter | Dry color value | Moist color value |
|------|-----------------------|----------------|-----------------|-------------------|
| 9    | road side             | 3.65           | 6.0             | 4.5               |
| 31   | non forested riparian | 8.06           | 6.0             | 3.5               |
| 24   | residential           | 4.96           | 5.0             | 3.0               |
| 22   | forested riparian     | 5.97           | 4.5             | 3.0               |
| 12   | forested riparian     | 8.54           | 3.0             | 2.5               |
| 23   | forested riparian     | 10.44          | 3.0             | 2.0               |

**Table 15.** Color value and organic matter content of the six samples composing the color spectrum of upland soil samples used in making the regression model.

| Plot | Land use        | Organic matter | Dry color value | Moist color value |
|------|-----------------|----------------|-----------------|-------------------|
| 29   | irrigated wheat | 0.88           | 7.0             | 5.5               |
| 5    | wheat fallow    | 1.21           | 6.0             | 4.0               |
| 27   | CRP             | 1.53           | 6.0             | 4.0               |
| 1    | CRP             | 1.84           | 5.5             | 4.5               |
| 20   | native range    | 1.59           | 5.0             | 4.5               |
| 11   | road side       | 1.78           | 4.5             | 4.0               |

The linear regression model for upland moist color values is:

$$OM = -3.771 * \text{moist value} + 3.1371$$

Using dry color value produced a better fit of the linear regression model to the data than moist values, adjusted  $r^2 = 0.65$  for the dry value verses adjusted  $r^2 = 0.21$  for moist value (Figures 36 and 37). The upland samples had a much smaller range of soil organic matter content, 0.8 to 1.8 percent, than did the valley bottom samples, 3.6 to 10.4 percent. We tested the predictive capability of each model by determining whether or not values from the independent data set predicted soil organic matter to within 0.5 percent. The moist value valley bottom model predicted organic matter to within 0.5 percent in only 10 percent of the cases. The dry value model did not predict soil organic matter to within 0.5 percent in any cases (Table 18). The moist value model for the upland predicted organic

matter to within 0.5 percent, in 67 percent of the cases (Table 19). The upland dry model predicted to within 0.5 percent of measured organic matter in 61 percent of the cases (Table 19).

**Table 16.** Regression analyses results from the six valley bottom samples used to build the organic matter prediction models.

| Moist value model results |                    |         |                         |
|---------------------------|--------------------|---------|-------------------------|
| Variable                  | Parameter estimate | P-value | Adjusted r <sup>2</sup> |
| Intercept                 | 14.15              | 0.01    | 0.55                    |
| Moist value               | -2.34              | 0.06    |                         |
| Dry value model results   |                    |         |                         |
| Variable                  | Parameter estimate | P-value | Adjusted r <sup>2</sup> |
| Intercept                 | 12.86              | 0.02    | 0.35                    |
| Dry value                 | -1.29              | 0.12    |                         |

**Table 17.** Regression analyses results from the six upland samples used to build the organic matter prediction models.

| Moist value model results |                    |         |                         |
|---------------------------|--------------------|---------|-------------------------|
| Variable                  | Parameter estimate | p-value | Adjusted r <sup>2</sup> |
| Intercept                 | 3.14               | 0.05    | 0.21                    |
| Moist value               | -0.38              | 0.20    |                         |
| Dry value model results   |                    |         |                         |
| Variable                  | Parameter estimate | p-value | Adjusted r <sup>2</sup> |
| Intercept                 | 3.48               | 0.01    | 0.65                    |
| Dry value                 | -0.35              | 0.03    |                         |

**Table 18.** Summary of predictions from the two valley bottom models.

| Plot Land use           | Dry<br>value | Moist<br>value | Dry model<br>predicted % OM | Moist model<br>predicted % OM | % OM<br>measured |
|-------------------------|--------------|----------------|-----------------------------|-------------------------------|------------------|
| 2 ungrazed bottom       | 4.0          | 4.0            | 7.67                        | 4.79                          | 3.04             |
| 9 valley bottom highway | 6.0          | 4.5            | 5.08                        | 3.62                          | 3.65             |
| 12 forested riparian    | 3.0          | 2.5            | 8.97                        | 8.30                          | 8.54             |
| 14 residential          | 5.0          | 3.0            | 6.38                        | 7.13                          | 4.57             |
| 15 residential          | 4.0          | 3.0            | 7.67                        | 7.13                          | 4.86             |
| 16 grazed bottom        | 4.5          | 3.0            | 7.02                        | 7.13                          | 3.22             |
| 17 non forest ripar.    | 4.5          | 2.5            | 7.02                        | 8.30                          | 5.2              |
| 18 non forest ripar.    | 5.0          | 3.5            | 6.38                        | 5.96                          | 10.93            |
| 19 bottom dry hay       | 4.0          | 2.0            | 7.67                        | 9.47                          | 6.46             |
| 22 forested riparian    | 4.5          | 3.0            | 7.02                        | 7.13                          | 5.97             |
| 23 forested riparian    | 3.0          | 2.0            | 8.97                        | 9.47                          | 10.44            |
| 24 residential          | 5.0          | 3.0            | 6.38                        | 7.13                          | 4.96             |
| 31 non forest ripar.    | 6.0          | 3.5            | 5.08                        | 5.96                          | 8.06             |
| 32 grazed bottom        | 5.5          | 4.0            | 5.73                        | 4.79                          | 4.59             |
| 12 low highway          | 4.5          | 3.0            | 7.02                        | 7.13                          | 3.08             |
| 17 low highway          | 4.0          | 2.0            | 7.67                        | 9.47                          | 4.49             |

**Table 19.** Summary of predictions from the two upland models.

| Plot | Land Use     | Dry value | Wet value | Dry model<br>predicted %<br>organic Matter | Moist model<br>predicted %<br>organic Matter | %OM<br>Measured |
|------|--------------|-----------|-----------|--------------------------------------------|----------------------------------------------|-----------------|
| 1    | CRP          | 5.0       | 4.5       | 1.71                                       | 1.44                                         | 1.48            |
| 2    | CRP          | 5.5       | 4.5       | 1.53                                       | 1.44                                         | 1.63            |
| 3    | shrub range  | 5.0       | 3.5       | 1.71                                       | 1.82                                         | 2.79            |
| 4    | shrub range  | 5.0       | 3.5       | 1.71                                       | 1.82                                         | 2.82            |
| 5    | shrub range  | 5.5       | 4.5       | 1.53                                       | 1.44                                         | 2.48            |
| 6    | shrub range  | 5.5       | 3.5       | 1.53                                       | 1.82                                         | 2.55            |
| 7    | shrub range  | 5.5       | 3.5       | 1.53                                       | 1.82                                         | 2.50            |
| 8    | irr wheat    | 6.0       | 4.5       | 1.35                                       | 1.44                                         | 1.76            |
| 9    | irr alfalfa  | 6.5       | 4.0       | 1.18                                       | 1.63                                         | 1.57            |
| 10   | hay          | 5.5       | 4.5       | 1.53                                       | 1.44                                         | 1.41            |
| 11   | crop fallow  | 5.0       | 4.0       | 1.71                                       | 1.63                                         | 1.32            |
| 13   | crop fallow  | 5.5       | 4.0       | 1.53                                       | 1.63                                         | 1.51            |
| 14   | hay          | 5.5       | 4.0       | 1.53                                       | 1.63                                         | 1.94            |
| 15   | shrub range  | 5.5       | 4.0       | 1.53                                       | 1.63                                         | 1.72            |
| 16   | up roadside  | 5.0       | 4.5       | 1.71                                       | 1.44                                         | 1.82            |
| 18   | CRP          | 5.0       | 4.0       | 1.71                                       | 1.63                                         | 1.33            |
| 19   | seeded range | 6.0       | 4.5       | 1.35                                       | 1.44                                         | 2.46            |
| 20   | CRP          | 5.5       | 4.0       | 1.53                                       | 1.63                                         | 2.38            |
| 21   | CRP          | 5.5       | 4.0       | 1.53                                       | 1.63                                         | 2.35            |
| 22   | seeded range | 5.5       | 3.5       | 1.53                                       | 1.82                                         | 2.07            |
| 23   | commercial   | 7.0       | 5.0       | 1.00                                       | 1.25                                         | 0.46            |
| 1    | CRP          | 5.5       | 4.5       | 1.53                                       | 1.44                                         | 1.84            |
| 3    | CRP          | 6.0       | 4.5       | 1.35                                       | 1.44                                         | 1.41            |
| 5    | crop fallow  | 6.0       | 4.0       | 1.35                                       | 1.63                                         | 1.21            |
| 6    | crop fallow  | 5.0       | 5.5       | 1.71                                       | 1.06                                         | 1.29            |
| 7    | shrub range  | 5.5       | 4.0       | 1.53                                       | 1.63                                         | 2.07            |
| 8    | Irr. wheat   | 6.5       | 4.5       | 1.18                                       | 1.44                                         | 2.7             |
| 10   | up roadside  | 5.0       | 4.0       | 1.71                                       | 1.63                                         | 1.71            |
| 11   | up roadside  | 4.5       | 4.0       | 1.88                                       | 1.63                                         | 1.78            |
| 13   | shrub range  | 5.0       | 3.5       | 1.71                                       | 1.82                                         | 1.49            |
| 20   | shrub range  | 5.0       | 4.5       | 1.71                                       | 1.44                                         | 1.59            |
| 21   | seeded range | 5.5       | 4.0       | 1.53                                       | 1.63                                         | 1.9             |
| 25   | hay          | 5.5       | 4.0       | 1.53                                       | 1.63                                         | 2.05            |
| 26   | CRP          | 6.0       | 5.5       | 1.35                                       | 1.06                                         | 1               |
| 27   | CRP          | 6.0       | 4.0       | 1.35                                       | 1.63                                         | 1.53            |
| 28   | CRP          | 5.5       | 4.5       | 1.53                                       | 1.44                                         | 1.19            |
| 29   | Irr. wheat   | 7.0       | 5.5       | 1.00                                       | 1.06                                         | 0.88            |
| 30   | Irr. alfalfa | 7.0       | 5.0       | 1.00                                       | 1.25                                         | 1.35            |
| 33   | hay          | 6.5       | 4.5       | 1.18                                       | 1.44                                         | 0.81            |

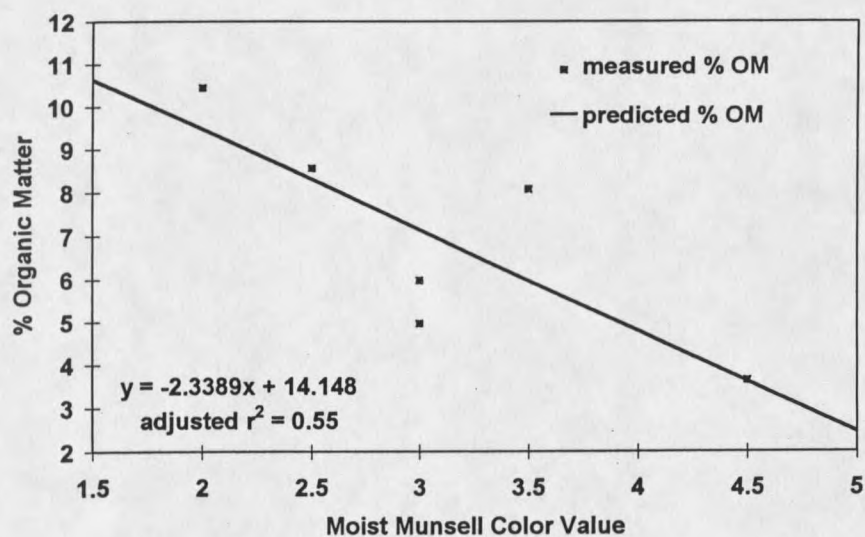


**Figure 34.** Linear regression of moist color value vs. soil organic matter for the valley bottom.

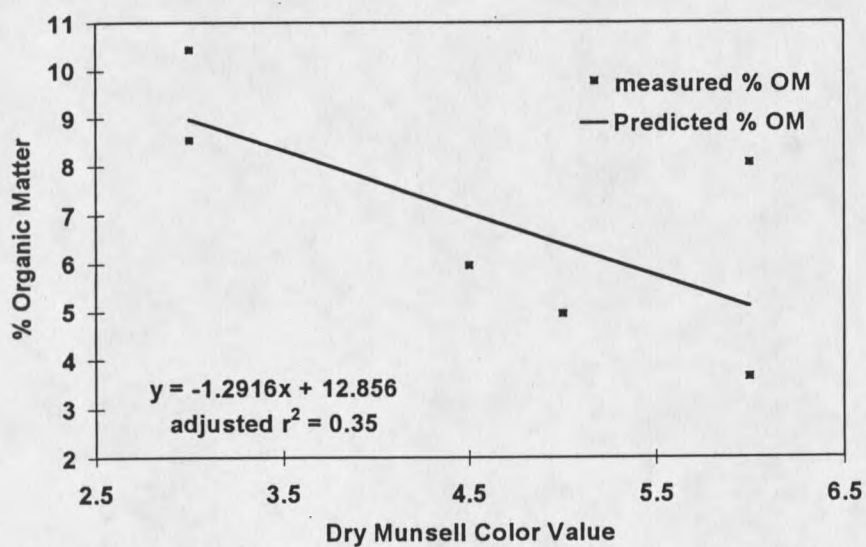


**Figure 35.** Linear regression of dry color value vs. soil organic matter for the valley bottom.

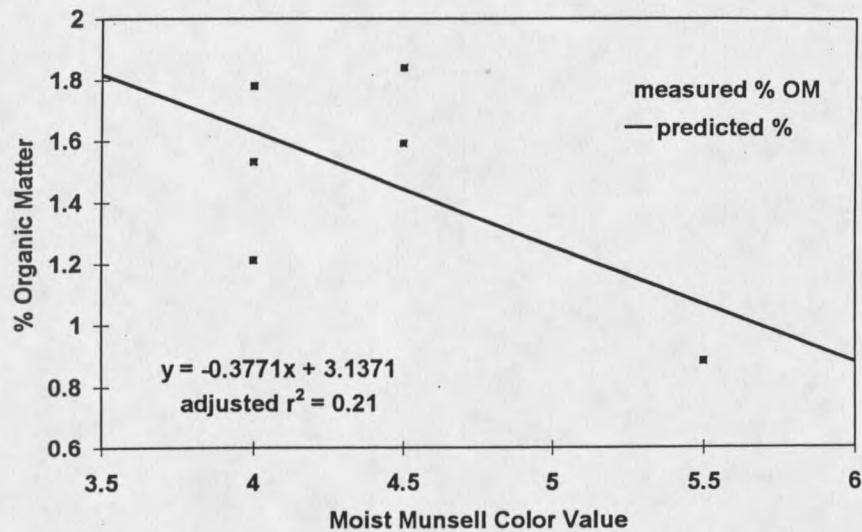


Figure 36. Linear regression of moist color value vs. soil organic matter for the upland.

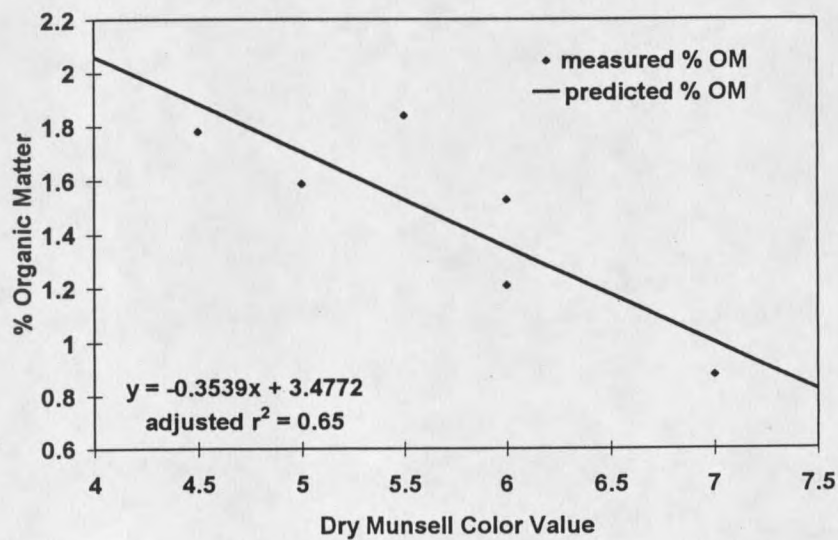


Figure 37. Linear regression of dry color value vs. soil organic matter for the upland.

### Discussion

The relationship between Munsell color value and soil organic matter across different land uses on the same landform was not as strong as the relationships found by Zelenak (1995) in one field, or statewide after stratifying by land cover. These results suggest that the effect of land use on soil color could limit the usefulness of a color - organic matter prediction model at the landform scale.

The upland model for dry values had a higher adjusted  $r^2$ , 0.65 versus 0.21, than the moist value model, however the moist value model predicted percent organic matter to within 0.5 percent more often, 67 percent versus 61 percent. Considering the small range of percent organic matter in the upland, 0.8 to 1.8, 67 percent predictability is not precise enough for comparisons between land uses. A further study across multiple fields within the same land use on the same landform would show if a strong relationship between color and organic matter could be established at the landform scale.

### Summary

The best model for predicting percent soil organic matter in the upland landform was

$$OM = -3771 * \text{moist value} + 3.1371.$$

This model predicted percent organic matter to within 0.5 percent in 67 percent of the cases using an independent data set.

The best model for predicting percent soil organic matter in the valley bottom was

$$OM = -2.3389 * \text{moist value} + 14.148.$$

This model predicted percent organic matter to within 0.5 percent in only 10 percent of the cases using an independent data set. Neither the upland model nor the valley bottom model is precise enough to use for monitoring changes in organic matter content across different land uses within the same landform in the Three Forks study area.

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**APPENDICES**

**APPENDIX A**

**CHAPTER 1 TABLES**

**Table 20.** Regression results for all 1995 upland grid units, using actual EI as the dependent variable versus each scaled variable score.

| measure                       | r     | r <sup>2</sup> | p     | slope  |
|-------------------------------|-------|----------------|-------|--------|
| bare soil                     | 0.767 | 0.562          | 0.000 | 0.253  |
| rock or pavement              | 0.148 | -0.039         | 0.559 | 0.046  |
| moss cover                    | 0.737 | 0.515          | 0.000 | 0.203  |
| litter cover                  | 0.736 | 0.512          | 0.001 | 0.228  |
| canopy cover                  | 0.072 | -0.057         | 0.777 | 0.023  |
| root biomass                  | 0.679 | 0.428          | 0.002 | 0.270  |
| standing live biomass         | 0.262 | 0.011          | 0.293 | -0.079 |
| standing dead biomass         | 0.364 | 0.079          | 0.137 | 0.122  |
| litter biomass                | 0.448 | 0.151          | 0.062 | 0.146  |
| water infiltration rate       | 0.114 | -0.049         | 0.652 | 0.035  |
| soil bulk density             | 0.198 | -0.021         | 0.431 | 0.163  |
| soil respiration              | 0.141 | -0.041         | 0.576 | -0.040 |
| mammal taxons                 | 0.547 | 0.255          | 0.019 | 0.155  |
| arthropod taxons              | 0.305 | 0.037          | 0.218 | 0.092  |
| soil potassium                | 0.213 | -0.014         | 0.396 | 0.086  |
| total soil nitrogen           | 0.274 | 0.017          | 0.272 | 0.151  |
| soil organic matter           | 0.389 | 0.098          | 0.111 | 0.188  |
| soil carbon/ nitrogen         | 0.558 | 0.268          | 0.016 | 0.457  |
| soil phosphorus               | 0.683 | 0.433          | 0.002 | 0.224  |
| soil nitrate                  | 0.594 | 0.272          | 0.069 | 0.251  |
| plant morphological diversity | 0.316 | 0.044          | 0.201 | 0.093  |
| plant species richness        | 0.742 | 0.522          | 0.000 | 0.215  |
| weeds                         | 0.299 | 0.033          | 0.228 | 0.074  |
| plant canopy diversity        | 0.237 | -0.003         | 0.344 | 0.062  |
| soil nitrate/ nitrogen        | 0.458 | 0.160          | 0.056 | 0.132  |
| standing live/litter biomass  | 0.443 | 0.146          | 0.066 | -0.123 |

**Table 21.** Regression results for all 1996 upland grid units, using actual EI as the dependent variable versus each scaled variable score.

| measure                       | r     | r <sup>2</sup> | p     | slope  |
|-------------------------------|-------|----------------|-------|--------|
| bare soil                     | 0.450 | 0.161          | 0.040 | 0.208  |
| rock or pavement              | 0.593 | 0.318          | 0.005 | 0.371  |
| moss cover                    | 0.014 | -0.052         | 0.952 | -0.007 |
| litter cover                  | 0.331 | 0.063          | 0.142 | 0.169  |
| canopy cover                  | 0.427 | 0.140          | 0.053 | 0.255  |
| root biomass                  | 0.739 | 0.522          | <.001 | 0.312  |
| standing live biomass         | 0.281 | 0.030          | 0.217 | 0.177  |
| standing dead biomass         | 0.173 | -0.021         | 0.452 | 0.113  |
| litter biomass                | 0.272 | 0.025          | 0.233 | 0.151  |
| water infiltration rate       | 0.733 | 0.513          | <.001 | 0.376  |
| soil bulk density             | 0.707 | 0.474          | <.001 | 0.447  |
| soil respiration              | 0.362 | 0.085          | 0.107 | 0.203  |
| mammal taxons                 | 0.584 | 0.306          | 0.005 | 0.303  |
| arthropod taxons              | 0.438 | 0.150          | 0.047 | 0.191  |
| soil potassium                | 0.612 | 0.342          | 0.003 | 0.313  |
| total soil nitrogen           | 0.696 | 0.457          | <.001 | 0.432  |
| soil organic matter           | 0.794 | 0.611          | <.001 | 0.422  |
| soil carbon/ nitrogen         | 0.506 | 0.217          | 0.019 | 0.247  |
| soil phosphorus               | 0.419 | 0.132          | 0.059 | 0.269  |
| soil nitrate                  | 0.565 | 0.284          | 0.008 | 0.246  |
| plant morphological diversity | 0.800 | 0.621          | <.001 | 0.301  |
| plant species richness        | 0.639 | 0.377          | 0.002 | 0.287  |
| weeds                         | 0.637 | 0.375          | 0.002 | 0.336  |
| plant canopy diversity        | 0.239 | 0.008          | 0.297 | 0.183  |
| soil nitrate/ nitrogen        | 0.754 | 0.547          | <.001 | 0.378  |
| standing live/litter biomass  | 0.287 | 0.032          | 0.219 | 0.115  |

**Table 22.** Regression results for resampled 1996 upland grid units, using actual EI as the dependent variable versus each scaled variable score.

| measure                       | r     | r <sup>2</sup> | p     | slope  |
|-------------------------------|-------|----------------|-------|--------|
| bare soil                     | 0.637 | 0.331          | 0.047 | 0.161  |
| rock or pavement              | 0.253 | 0.052          | 0.479 | -0.267 |
| moss cover                    | 0.696 | 0.42           | 0.025 | 0.137  |
| litter cover                  | 0.521 | 0.18           | 0.122 | 0.099  |
| canopy cover                  | 0.017 | 0.124          | 0.961 | -0.004 |
| root biomass                  | 0.842 | 0.674          | 0.002 | 0.192  |
| standing live biomass         | 0.362 | 0.023          | 0.302 | -0.062 |
| standing dead biomass         | 0.326 | 0.005          | 0.357 | -0.101 |
| litter biomass                | 0.15  | 0.099          | 0.677 | 0.053  |
| water infiltration rate       | 0.179 | 0.088          | 0.62  | -0.051 |
| soil bulk density             | 0.184 | 0.086          | 0.608 | 0.11   |
| soil respiration              | 0.248 | 0.055          | 0.489 | -0.05  |
| mammal taxons                 | 0.548 | 0.213          | 0.1   | 0.235  |
| arthropod taxons              | 0.315 | 0.012          | 0.373 | 0.204  |
| soil potassium                | 0.387 | 0.044          | 0.268 | 0.101  |
| total soil nitrogen           | 0.791 | 0.58           | 0.006 | 0.359  |
| soil organic matter           | 0.818 | 0.627          | 0.003 | 0.291  |
| soil carbon/ nitrogen         | 0.612 | 0.297          | 0.059 | 0.35   |
| soil phosphorus               | 0.634 | 0.328          | 0.048 | -0.165 |
| soil nitrate                  | 0.594 | 0.272          | 0.069 | 0.251  |
| plant morphological diversity | 0.696 | 0.421          | 0.025 | 0.154  |
| plant species richness        | 0.795 | 0.586          | 0.005 | 0.179  |
| weeds                         | 0.377 | 0.035          | 0.282 | 0.063  |
| plant canopy diversity        | 0.302 | 0.021          | 0.395 | 0.099  |
| soil nitrate/ nitrogen        | 0.658 | 0.362          | 0.038 | 0.234  |
| standing live/litter biomass  | 0.203 | 0.078          | 0.572 | -0.045 |

**Table 23.** Regression results for resampled 1996 upland grid units, using actual EI as the dependent variable versus each scaled variable score.

| measure                       | r     | r <sup>2</sup> | p     | slope  |
|-------------------------------|-------|----------------|-------|--------|
| bare soil                     | 0.774 | 0.548          | 0.009 | 0.226  |
| rock or pavement              | 0.285 | 0.033          | 0.425 | -0.085 |
| moss cover                    | 0.741 | 0.493          | 0.014 | 0.184  |
| litter cover                  | 0.55  | 0.215          | 0.099 | 0.173  |
| canopy cover                  | 0.059 | 0.121          | 0.871 | 0.018  |
| root biomass                  | 0.442 | 0.096          | 0.2   | 0.609  |
| standing live biomass         | 0.134 | 0.105          | 0.711 | 0.128  |
| standing dead biomass         | 0.252 | 0.053          | 0.481 | -0.074 |
| litter biomass                | 0.168 | 0.093          | 0.643 | -0.057 |
| water infiltration rate       | 0.155 | 0.098          | 0.668 | 0.05   |
| soil bulk density             | 0.24  | 0.06           | 0.505 | 0.21   |
| soil respiration              | 0.697 | 0.422          | 0.025 | 0.23   |
| mammal taxons                 | 0.551 | 0.216          | 0.099 | 0.162  |
| arthropod taxons              | 0.292 | 0.029          | 0.413 | 0.113  |
| soil potassium                | 0.118 | 0.109          | 0.745 | 0.061  |
| total soil nitrogen           | 0.646 | 0.345          | 0.043 | 0.429  |
| soil organic matter           | 0.587 | 0.263          | 0.074 | 0.328  |
| soil carbon/ nitrogen         | 0.182 | 0.088          | 0.615 | 0.213  |
| soil phosphorus               | 0.62  | 0.308          | 0.056 | -0.186 |
| soil nitrate                  | 0.758 | 0.521          | 0.011 | 0.166  |
| plant morphological diversity | 0.871 | 0.729          | 0.001 | 0.215  |
| plant species richness        | 0.824 | 0.638          | 0.003 | 0.218  |
| weeds                         | 0.471 | 0.124          | 0.17  | -0.169 |
| plant canopy diversity        | 0.501 | 0.167          | 0.132 | 0.136  |
| soil nitrate/nitrogen         | 0.783 | 0.564          | 0.007 | 0.173  |
| standing live/litter biomass  | 0.424 | 0.077          | 0.222 | 0.921  |

**Table 24.** Regression results for all 1995 upland grid units, using referenced EI as the dependent variable versus each scaled variable score.

| measure                       | r    | r <sup>2</sup> | p    | slope |
|-------------------------------|------|----------------|------|-------|
| bare soil                     | .780 | .582           | .000 | -.228 |
| rock or pavement              | .300 | .029           | .243 | -.134 |
| moss cover                    | .615 | .336           | .009 | -.190 |
| litter cover                  | .837 | .681           | .000 | -.239 |
| canopy cover                  | .571 | .281           | .017 | -.167 |
| root biomass                  | .637 | .367           | .006 | -.301 |
| standing live biomass         | .541 | .245           | .025 | -.180 |
| standing dead biomass         | .352 | .065           | .166 | .133  |
| litter biomass                | .372 | .081           | .142 | .136  |
| water infiltration rate       | .062 | -.063          | .814 | .022  |
| soil bulk density             | .266 | .009           | .303 | .093  |
| soil respiration              | .100 | -.056          | .702 | -.038 |
| mammal taxons                 | .226 | -.012          | .382 | -.056 |
| arthropod taxons              | .193 | -.027          | .458 | .058  |
| soil potassium                | .400 | .104           | .112 | .152  |
| total soil nitrogen           | .341 | .057           | .181 | -.119 |
| soil organic matter           | .638 | .367           | .006 | -.246 |
| soil carbon/ nitrogen         | .706 | .465           | .002 | -.270 |
| soil phosphorus               | .841 | .688           | .000 | -.276 |
| soil nitrate                  | .528 | .231           | .029 | -.201 |
| plant morphological diversity | .423 | .124           | .091 | -.124 |
| plant species richness        | .621 | .345           | .008 | -.182 |
| weeds                         | .050 | -.064          | .850 | .014  |
| plant canopy diversity        | .152 | -.042          | .560 | -.057 |
| soil nitrate/nitrogen         | .596 | .312           | .012 | -.182 |
| standing live/litter biomass  | .730 | .502           | .001 | -.259 |

**Table 25.** Regression results for all 1996 upland grid units, using referenced EI as the dependent variable versus each scaled referenced variable score.

| measure                       | r     | r <sup>2</sup> | p     | slope  |
|-------------------------------|-------|----------------|-------|--------|
| bare soil                     | 0.614 | 0.344          | 0.003 | -0.241 |
| rock or pavement              | 0.698 | 0.459          | 0.001 | -0.290 |
| moss cover                    | 0.556 | 0.271          | 0.011 | -0.151 |
| litter cover                  | 0.484 | 0.192          | 0.030 | -0.149 |
| canopy cover                  | 0.432 | 0.142          | 0.057 | -0.174 |
| root biomass                  | 0.673 | 0.423          | 0.001 | -0.197 |
| standing live biomass         | 0.155 | -0.030         | 0.513 | -0.064 |
| standing dead biomass         | 0.010 | -0.055         | 0.965 | -0.004 |
| litter biomass                | 0.113 | -0.042         | 0.637 | -0.043 |
| water infiltration rate       | 0.647 | 0.387          | 0.002 | -0.219 |
| soil bulk density             | 0.573 | 0.291          | 0.008 | -0.252 |
| soil respiration              | 0.487 | 0.195          | 0.029 | -0.176 |
| mammal taxons                 | 0.311 | 0.046          | 0.182 | -0.100 |
| arthropod taxons              | 0.334 | 0.062          | 0.150 | -0.109 |
| soil potassium                | 0.083 | -0.048         | 0.727 | 0.032  |
| total soil nitrogen           | 0.338 | 0.065          | 0.145 | -0.146 |
| soil organic matter           | 0.214 | -0.007         | 0.364 | -0.067 |
| soil carbon/ nitrogen         | 0.156 | -0.030         | 0.510 | 0.064  |
| soil phosphorus               | 0.382 | 0.099          | 0.096 | -0.136 |
| soil nitrate                  | 0.584 | 0.305          | 0.007 | -0.169 |
| plant morphological diversity | 0.709 | 0.475          | 0.000 | -0.183 |
| plant species richness        | 0.554 | 0.269          | 0.011 | -0.174 |
| weeds                         | 0.218 | -0.006         | 0.357 | 0.077  |
| plant canopy diversity        | 0.008 | -0.055         | 0.974 | -0.004 |
| soil nitrate/nitrogen         | 0.837 | 0.684          | 0.000 | -0.280 |
| standing live/litter biomass  | 0.362 | 0.083          | 0.117 | -0.146 |

**Table 26.** Regression results for resampled 1995 upland grid units, using referenced EI as the dependent variable versus each scaled referenced variable score.

| measure                       | r     | r <sup>2</sup> | p     | slope  |
|-------------------------------|-------|----------------|-------|--------|
| bare soil                     | 0.776 | 0.546          | 0.014 | -0.164 |
| rock or pavement              | 0.004 | -0.143         | 0.991 | -0.016 |
| moss cover                    | 0.685 | 0.393          | 0.042 | -0.217 |
| litter cover                  | 0.789 | 0.569          | 0.011 | -0.177 |
| canopy cover                  | 0.518 | 0.164          | 0.153 | -0.345 |
| root biomass                  | 0.718 | 0.447          | 0.029 | -0.268 |
| standing live biomass         | 0.462 | 0.101          | 0.211 | -0.100 |
| standing dead biomass         | 0.592 | 0.258          | 0.093 | 0.133  |
| litter biomass                | 0.330 | -0.018         | 0.385 | 0.117  |
| water infiltration rate       | 0.153 | -0.116         | 0.694 | -0.062 |
| soil bulk density             | 0.361 | 0.006          | 0.340 | 0.086  |
| soil respiration              | 0.387 | 0.028          | 0.304 | -0.114 |
| mammal taxons                 | 0.575 | 0.234          | 0.106 | -0.162 |
| arthropod taxons              | 0.239 | -0.078         | 0.536 | 0.059  |
| soil potassium                | 0.326 | -0.021         | 0.392 | 0.094  |
| total soil nitrogen           | 0.074 | -0.137         | 0.849 | 0.022  |
| soil organic matter           | 0.473 | 0.113          | 0.198 | -0.133 |
| soil carbon/nitrogen          | 0.805 | 0.598          | 0.009 | -0.223 |
| soil phosphorus               | 0.920 | 0.825          | 0.000 | -0.408 |
| soil nitrate                  | 0.728 | 0.462          | 0.026 | -0.918 |
| plant morphological diversity | 0.560 | 0.215          | 0.117 | -0.135 |
| plant species richness        | 0.445 | 0.083          | 0.230 | -0.137 |
| weeds                         | 0.197 | -0.098         | 0.611 | -0.042 |
| plant canopy diversity        | 0.085 | -0.135         | 0.827 | -0.026 |
| soil nitrate/nitrogen         | 0.736 | 0.476          | 0.024 | -0.864 |
| standing live/litter biomass  | 0.690 | 0.401          | 0.040 | -0.178 |

**Table 27.** Regression results for resampled 1996 upland grid units, using referenced EI as the dependent variable versus each scaled variable score.

| measure                       | r    | r <sup>2</sup> | p    | slope  |
|-------------------------------|------|----------------|------|--------|
| bare soil                     | .699 | .416           | .036 | -.159  |
| rock or pavement              | .279 | -.054          | .466 | .067   |
| moss cover                    | .784 | .560           | .012 | -.228  |
| litter cover                  | .469 | .109           | .203 | -.105  |
| canopy cover                  | .494 | .136           | .177 | -.116  |
| root biomass                  | .534 | .183           | .139 | -.124  |
| standing live biomass         | .024 | -.142          | .950 | -.116  |
| standing dead biomass         | .031 | -.142          | .936 | .017   |
| litter biomass                | .107 | -.130          | .785 | .061   |
| water infiltration rate       | .255 | -.069          | .508 | -.050  |
| soil bulk density             | .240 | -.077          | .535 | .060   |
| soil respiration              | .576 | .236           | .105 | -.413  |
| mammal taxons                 | .118 | -.127          | .762 | -.024  |
| arthropod taxons              | .027 | -.142          | .944 | -.011  |
| soil potassium                | .138 | -.121          | .723 | .060   |
| total soil nitrogen           | .455 | .094           | .218 | .210   |
| soil organic matter           | .312 | -.031          | .413 | .083   |
| soil carbon/ nitrogen         | .142 | -.120          | .716 | .053   |
| soil phosphorus               | .534 | .183           | .138 | -.127  |
| soil nitrate                  | .711 | .434           | .032 | -.125  |
| plant morphological diversity | .690 | .401           | .040 | -.125  |
| plant species richness        | .617 | .293           | .076 | -.151  |
| weeds                         | .297 | -.042          | .438 | 49.923 |
| plant canopy diversity        | .231 | -.082          | .550 | .098   |
| soil nitrate/nitrogen         | .721 | .451           | .028 | -.128  |
| standing live/litter biomass  | .317 | -.028          | .405 | -4.319 |

**Table 28.** Regression results for all 1995 and 1996 valley bottom grid units, using referenced EI as the dependent variable versus each scaled referenced variable score.

| measure                       | r     | r <sup>2</sup> | p     | slope  |
|-------------------------------|-------|----------------|-------|--------|
| %bare soil                    | 0.129 | -0.045         | 0.611 | 0.055  |
| basal vegetation cover        | 0.213 | -0.014         | 0.395 | 0.127  |
| rock or pavement              | 0.840 | 0.687          | 0.000 | 0.360  |
| moss cover                    | 0.013 | -0.062         | 0.960 | 0.007  |
| litter                        | 0.853 | 0.711          | 0.000 | 0.371  |
| downed wood                   | 0.411 | 0.117          | 0.090 | 0.169  |
| animal feces                  | 0.293 | 0.028          | 0.239 | 0.109  |
| canopy cover                  | 0.690 | 0.443          | 0.002 | 0.350  |
| high canopy cover             | 0.466 | 0.168          | 0.051 | 0.198  |
| low canopy cover              | 0.571 | 0.284          | 0.013 | 0.264  |
| medium canopy cover           | 0.473 | 0.176          | 0.047 | 0.213  |
| root biomass                  | 0.728 | 0.500          | 0.001 | 0.317  |
| standing live plant biomass   | 0.279 | 0.020          | 0.263 | 0.163  |
| standing dead plant biomass   | 0.175 | -0.030         | 0.487 | 0.101  |
| litter biomass                | 0.403 | 0.110          | 0.097 | 0.205  |
| water infiltration rate       | 0.762 | 0.555          | 0.000 | 0.363  |
| soil bulk density             | 0.479 | 0.174          | 0.061 | 0.215  |
| soil respiration rate         | 0.559 | 0.270          | 0.016 | 0.234  |
| mammal taxons                 | 0.119 | -0.048         | 0.639 | 0.049  |
| arthropod taxons              | 0.281 | 0.021          | 0.259 | 0.135  |
| soil potassium                | 0.031 | -0.070         | 0.908 | 0.036  |
| total soil nitrogen           | 0.035 | -0.070         | 0.896 | 0.043  |
| soil organic matter           | 0.130 | -0.053         | 0.630 | 0.153  |
| soil carbon/ nitrogen         | 0.110 | -0.059         | 0.686 | 0.243  |
| soil phosphorus               | 0.450 | 0.146          | 0.080 | -0.443 |
| soil nitrate                  | 0.402 | 0.101          | 0.123 | 0.407  |
| plant morphological diversity | 0.639 | 0.371          | 0.004 | 0.256  |
| plant species richness        | 0.457 | 0.159          | 0.057 | 0.225  |
| weeds                         | 0.147 | -0.039         | 0.560 | 0.078  |
| plant canopy diversity        | 0.518 | 0.223          | 0.028 | 0.191  |
| soil nitrate/total nitrogen   | 0.147 | -0.048         | 0.586 | 0.037  |
| live/litter biomass           | 0.154 | -0.046         | 0.569 | 0.038  |

**Table 29.** Regression results for all 1995 and 1996 valley bottom grid units, using referenced EI as the dependent variable versus each scaled referenced variable score

| measure                       | r     | r <sup>2</sup> | p     | slope  |
|-------------------------------|-------|----------------|-------|--------|
| bare soil                     | 0.034 | -0.065         | 0.896 | 0.012  |
| basal vegetation cover        | 0.077 | -0.060         | 0.768 | -0.036 |
| rock or pavement              | 0.730 | 0.501          | 0.001 | -0.253 |
| moss cover                    | 0.035 | -0.065         | 0.893 | -0.015 |
| litter                        | 0.672 | 0.415          | 0.003 | -0.240 |
| downed wood                   | 0.572 | 0.282          | 0.017 | -0.217 |
| animal feces                  | 0.201 | -0.024         | 0.440 | 0.065  |
| canopy cover                  | 0.742 | 0.521          | 0.001 | -0.241 |
| high canopy cover             | 0.622 | 0.346          | 0.008 | -0.281 |
| low canopy cover              | 0.366 | 0.076          | 0.149 | -0.133 |
| medium canopy cover           | 0.488 | 0.187          | 0.047 | -0.250 |
| root biomass                  | 0.426 | 0.127          | 0.088 | -0.160 |
| standing live plant biomass   | 0.333 | 0.052          | 0.191 | -0.157 |
| standing dead plant biomass   | 0.113 | -0.053         | 0.665 | 0.053  |
| litter biomass                | 0.759 | 0.548          | 0.000 | -0.364 |
| water infiltration rate       | 0.804 | 0.624          | 0.000 | -0.299 |
| soil bulk density             | 0.478 | 0.177          | 0.052 | -0.185 |
| soil respiration rate         | 0.072 | -0.061         | 0.783 | -0.028 |
| mammal taxons                 | 0.166 | -0.037         | 0.524 | 0.056  |
| arthropod taxons              | 0.250 | 0.000          | 0.334 | 0.112  |
| soil potassium                | 0.247 | -0.011         | 0.374 | -0.054 |
| total soil nitrogen           | 0.406 | 0.101          | 0.133 | -0.125 |
| soil organic matter           | 0.352 | 0.056          | 0.199 | -0.104 |
| soil carbon/nitrogen          | 0.546 | 0.244          | 0.035 | -0.229 |
| soil phosphorus               | 0.320 | 0.034          | 0.244 | -0.086 |
| soil nitrate                  | 0.367 | 0.068          | 0.178 | -0.105 |
| plant morphological diversity | 0.705 | 0.464          | 0.002 | -0.232 |
| plant species richness        | 0.598 | 0.315          | 0.011 | -0.209 |
| weeds                         | 0.705 | 0.464          | 0.002 | -0.317 |
| plant canopy diversity        | 0.644 | 0.376          | 0.005 | -0.224 |
| soil nitrate/total nitrogen   | 0.207 | -0.031         | 0.458 | -0.054 |
| live/litter biomass           | 0.189 | -0.028         | 0.467 | -0.080 |

**Table 30.** Coefficient of variation of variable scores determined by the mean of the between year difference in measurements divided by the sample mean of each measurement among the resampled grid units.

| <b>variable</b>         | <b>mean yearly difference / sample mean (CV)</b> |
|-------------------------|--------------------------------------------------|
| bare soil               | 0.287                                            |
| rock                    | 1.589                                            |
| moss                    | 0.473                                            |
| litter                  | 0.393                                            |
| canopy                  | 0.660                                            |
| root biomass            | 1.099                                            |
| live clippings          | 1.250                                            |
| dead clippings          | 1.014                                            |
| litter clippings        | 0.577                                            |
| water infl. rt.         | 0.559                                            |
| bulk density            | 0.110                                            |
| soil respiration        | 1.020                                            |
| mammal taxons           | 1.030                                            |
| bug taxons              | 1.097                                            |
| soil K                  | 0.247                                            |
| soil N                  | 0.114                                            |
| soil organic matter     | 0.203                                            |
| soil carbon/nitrogen    | 0.132                                            |
| soil P                  | 0.305                                            |
| soil NO <sub>3</sub>    | 0.860                                            |
| plant morf. div.        | 0.466                                            |
| plant species           | 0.555                                            |
| weeds                   | 1.636                                            |
| plant canopy div.       | 0.960                                            |
| soil NO <sub>3</sub> /N | 0.792                                            |
| live/litter             | 1.047                                            |

**Table 31.** Raw data and plot information for 1995 sample grid units.

| grid unit | cover class | land use              | owner                         | Phone    |
|-----------|-------------|-----------------------|-------------------------------|----------|
| 1         | 292         | CRP                   | George Kahrl                  | 285-3651 |
| 2         | 51          | ungrazed bottom       | (airport)William Fairhurst    | 285-3515 |
| 3         | 292         | CRP                   | Pete, Stacy Vanolah           | 285-6647 |
| 4         | 17          | abon indust           | Gordon Doig                   | 547-3338 |
| 5         | 21          | drycrop/fallow        | Dennis Rahn                   | 285-6843 |
| 6         | 21          | drycrop/fallow        | Dennis Rahn                   | 285-6843 |
| 7         | 32          | shrub range           | Don Scofield                  | 285-6746 |
| 8         | 22          | irr wheat             | Dean Volkford                 | 285-3614 |
| 9         | 16          | valley bottom highway | highway department            | 582-3250 |
| 10        | 14          | highwayup             | highway department            | 582-3250 |
| 11        | 14          | highwayup             | highway department            | 582-3250 |
| 12        | 61          | forested riparian     | (wildlife & parks)Tom Greeson | 994-4042 |
| 13        | 32          | shrub range           | Don Scofield                  | 285-6746 |
| 14        | 11          | residential           | Various                       |          |
| 15        | 11          | residential           | Various                       |          |
| 16        | 34          | grazed bottom         | Nick, Gladys Buttleman        | 285-6665 |
| 17        | 62          | non forest ripar.     | Nick, Gladys Buttleman        | 285-6665 |
| 18        | 62          | non forest ripar.     | Leo Lane                      | 285-6688 |
| 19        | 5           | bottom dry hay        | Don Scofield                  | 285-6746 |
| 20        | 32          | shrub range           | George Kahrl                  | 285-3651 |
| 21        | 33          | seeded range          | George Kahrl                  | 285-3651 |
| 22        | 61          | forested riparian     | Nick, Gladys Buttleman        | 285-6665 |
| 23        | 61          | forested riparian     | Nick, Gladys Buttleman        | 285-6665 |
| 24        | 11          | residential           | Various                       |          |
| 25        | 23          | dry up hay            | David, Marie Hamilton         | 285-6622 |
| 26        | 292         | CRP                   | Pete, Stacy Vandolah          | 285-6647 |
| 27        | 292         | CRP                   | Stanley Kimm                  | 285-6695 |
| 28        | 292         | CRP                   | Mrs. Don Johnston             | 285-6629 |
| 29        | 22          | irr wheat             | Robert Lane                   | 285-6693 |
| 30        | 24          | irr alfalfa           | Robert Lane                   | 285-6693 |
| 31        | 62          | non forest ripar.     | Brian Lane                    | 285-3643 |
| 32        | 34          | grazed bottom         | Brian Lane                    | 285-3643 |
| 33        | 23          | dry up hay            | Robert Lane                   | 285-6693 |
| 34        | 15          | commercial            | various                       |          |
| 35        | 15          | industrial            | Luzenac America               | 285-5300 |

Table 31. Cont.

| grid<br>unit | address                       | X* | Y  | date   | land<br>form | BS | BV | water | rock  |
|--------------|-------------------------------|----|----|--------|--------------|----|----|-------|-------|
|              |                               |    |    |        |              | %  | %  | %     | %     |
| 1            | box 62 willow Creek           | 9  | 30 | 13-Jun | 1            | 33 | 9  | 0     | 0     |
| 2            | 105 3rd Ave E. box 247 TF     | 37 | 40 | 14-Jun | 0            | 33 | 11 | 0     | 0     |
| 3            | 4 KOA Rd. TF                  | 18 | 26 | 15-Jun | 1            | 34 | 5  | 0     | 2     |
| 4            | 4524 US Hwy 89 S. WSS         | 41 | 30 | 16-Jun | 0            | 11 | 1  | 0     | 4     |
| 5            | 154 Wheatland Rd TF           | 3  | 9  | 20-Jun | 1            | 82 | 1  | 0     | 0     |
| 6            | 154 Wheatland Rd TF           | 1  | 9  | 20-Jun | 1            | 79 | 4  | 0     | 0     |
| 7            | RTE 1 box 246 TF              | 43 | 20 | 23-Jun | 1            | 68 | 6  | 0     | 0     |
| 8            | 10770 US Hwy 287 TF           | 20 | 26 | 23-Jun | 1            | 68 | 3  | 0     | 3     |
| 9            | 201 W Tamarack Rd Bozeman     | 42 | 23 | 26-Jun | 0            | 1  | 5  | 0     | 0     |
| 10           | 201 W Tamarack Rd Bozeman     | 10 | 19 | 26-Jun | 1            | 29 | 3  | 0     | 0     |
| 11           | 201 W Tamarack Rd Bozeman     | 25 | 19 | 28-Jun | 1            | 16 | 3  | 0     | 0     |
| 12           | 1400 S 19 Ave Bozeman         | 22 | 33 | 28-Jun | 0            | 1  | 3  | 0     | 0     |
| 13           | RTE 1 box 246 TF              | 36 | 14 | 29-Jun | 1            | 46 | 4  | 0     | 0     |
| 14           |                               | 37 | 36 | 29-Jun | 0            | 8  | 4  | 0     | 14    |
| 15           |                               | 42 | 34 | 30-Jun | 0            | 12 | 33 | 0     | 23    |
| 16           | 4680 Old Yellowstone Trail TF | 35 | 36 | 5-Jul  | 0            | 45 | 4  | 0     | 1     |
| 17           | 4680 Old Yellowstone Trail TF | 27 | 37 | 5-Jul  | 0            | 29 | 4  | 1     | 0     |
| 18           | box 355 TF                    | 21 | 41 | 11-Jul | 0            | 2  | 6  | 0     | 0     |
| 19           | RTE 1 box 246 TF              | 46 | 23 | 11-Jul | 0            | 0  | 9  | 0     | 0     |
| 20           | box 62 willow Creek           | 1  | 22 | 12-Jul | 1            | 41 | 5  | 0     | 0     |
| 21           | box 62 willow Creek           | 1  | 21 | 12-Jul | 1            | 82 | 1  | 0     | 0     |
| 22           | 4680 Old Yellowstone Trail TF | 34 | 33 | 13-Jul | 0            | 8  | 2  | 1     | 0     |
| 23           | 4680 Old Yellowstone Trail TF | 32 | 33 | 13-Jul | 0            | 4  | 2  | 10    | 0     |
| 24           |                               | 43 | 38 | 14-Jul | 0            | 15 | 3  | 0     | 25    |
| 25           | 10895 US Hwy 287 TF           | 19 | 32 | 18-Jul | 1            | 39 | 2  | 0     | 0.08  |
| 26           | 4 KOA Rd. TF                  | 21 | 16 | 18-Jul | 1            | 78 | 2  | 0     | 0.21  |
| 27           | 16 Bunny DR. TF               | 18 | 11 | 19-Jul | 1            | 52 | 2  | 0     | 0.00  |
| 28           | 42 Wheatland Rd. TF           | 4  | 10 | 19-Jul | 1            | 31 | 0  | 0     | 0.79  |
| 29           | Lane Rd. box 97 TF            | 25 | 21 | 20-Jul | 1            | 96 | 2  | 0     | 0.00  |
| 30           | Lane Rd. box 97 TF            | 29 | 20 | 20-Jul | 1            | 96 | 2  | 0     | 0.00  |
| 31           | box 496 TF                    | 47 | 42 | 21-Jul | 0            | 1  | 4  | 0     | 0.00  |
| 32           | box 496 TF                    | 40 | 44 | 25-Jul | 0            | 25 | 3  | 0     | 0.00  |
| 33           | Lane Rd. box 97 TF            | 25 | 20 | 25-Jul | 1            | 43 | 3  | 0     | 0.39  |
| 34           |                               | 40 | 36 | 26-Jul | 0            | 0  | 0  | 0     | 99.78 |
| 35           | 2150 Bench Rd.                | 41 | 42 | 21-Jul | 0            | 7  | 0  | 0     | 92.50 |

\*X,Y= sample grid coordinates; land form, 0=valley bottom, 1=upland; BS=%bare soil;  
BV=%basal vegetation cover; water=%water cover; rock=%rock or pavement cover;

Table 31. Cont.

| grid<br>unit | *moss | litter | wood | feces | canopy | Can/hi | can/low | can/med | roots  | live  |
|--------------|-------|--------|------|-------|--------|--------|---------|---------|--------|-------|
|              | %     | %      | %    | %     | %      | %      | %       | %       | g.     | g.    |
| 1            | 24    | 41     | 0    | 1     | 49     | 0      | 49      | 0       | 1627.6 | 142.9 |
| 2            | 3     | 54     | 0    | 0     | 53     | 0      | 53      | 0       | 2440.5 | 62.2  |
| 3            | 27    | 45     | 0    | 0     | 28     | 0      | 28      | 0       | 1262.5 | 156.5 |
| 4            | 0     | 34     | 5    | 72    | 19     | 0      | 19      | 0       | 1.0    | 20.8  |
| 5            | 0     | 17     | 0    | 0     | 1      | 0      | 1       | 0       | 0.0    | 0.0   |
| 6            | 0     | 19     | 0    | 0     | 37     | 0      | 37      | 0       | 616.6  | 53.7  |
| 7            | 5     | 24     | 1    | 1     | 40     | 0      | 38      | 1       | 3156.2 | 62.7  |
| 8            | 0     | 7      | 0    | 0     | 23     | 0      | 23      | 0       | 1150.0 | 99.0  |
| 9            | 1     | 96     | 0    | 0     | 84     | 0      | 85      | 0       | 2484.3 | 48.6  |
| 10           | 37    | 51     | 0    | 0     | 40     | 0      | 40      | 0       | 1132.3 | 33.9  |
| 11           | 17    | 76     | 0    | 0     | 36     | 0      | 36      | 0       | 1431.6 | 59.2  |
| 12           | 1     | 94     | 6    | 0     | 52     | 14     | 33      | 14      | 4773.7 | 60.8  |
| 13           | 12    | 43     | 2    | 0     | 36     | 1      | 34      | 0       | 1628.7 | 42.7  |
| 14           | 0     | 74     | 1    | 0     | 52     | 5      | 50      | 0       | 1804.7 | 24.6  |
| 15           | 0     | 41     | 8    | 0     | 64     | 4      | 60      | 0       | 2425.0 | 51.0  |
| 16           | 5     | 47     | 0    | 4     | 42     | 0      | 42      | 0       | 3753.9 | 21.7  |
| 17           | 11    | 62     | 0    | 2     | 47     | 0      | 43      | 7       | 3056.7 | 56.6  |
| 18           | 0     | 92     | 0    | 5     | 75     | 0      | 74      | 0       | 4970.3 | 95.1  |
| 19           | 0     | 84     | 0    | 0     | 96     | 0      | 96      | 0       | 3395.8 | 468.1 |
| 20           | 18    | 46     | 0    | 0     | 36     | 0      | 31      | 4       | 1997.6 | 12.0  |
| 21           | 0     | 16     | 0    | 0     | 11     | 0      | 11      | 0       | 1024.3 | 35.6  |
| 22           | 3.22  | 80     | 4    | 5     | 34     | 3      | 27      | 8       | 2414.4 | 25.1  |
| 23           | 0.61  | 80     | 5    | 0     | 42     | 16     | 29      | 5       | 2672.5 | 61.3  |
| 24           | 0.00  | 58     | 0    | 0     | 48     | 5      | 44      | 7       | 1911.2 | 0.0   |
| 25           | 8.06  | 56     | 0    | 0     | 10     | 0      | 10      | 0       | 1102.4 | 39.8  |
| 26           | 3.63  | 21     | 0    | 0     | 32     | 0      | 32      | 0       | 526.4  | 33.0  |
| 27           | 1.00  | 47     | 0    | 0     | 48     | 0      | 48      | 0       | 1082.5 | 92.7  |
| 28           | 7.89  | 32     | 0    | 0     | 20     | 0      | 20      | 0       | 862.3  | 40.8  |
| 29           | 0.00  | 1      | 0    | 0     | 80     | 0      | 80      | 0       | 674.5  | 647.2 |
| 30           | 0.00  | 1      | 0    | 0     | 80     | 0      | 5       | 80      | 794.7  | 760.6 |
| 31           | 0.00  | 92     | 0    | 0     | 51     | 0      | 87      | 0       | 2151.0 | 154.5 |
| 32           | 9.44  | 65     | 0    | 2     | 42     | 0      | 42      | 0       | 4391.2 | 53.0  |
| 33           | 0.00  | 53     | 0    | 5     | 10     | 0      | 10      | 0       | 1038.0 | 27.5  |
| 34           | 0.00  | 0      | 0    | 0     | 1      | 0      | 0       | 0       | 0.0    | 28.5  |
| 35           | 0.00  | 0      | 0    | 0     | 0      | 0      | 0       | 0       | 0.0    | 0.0   |

\*moss=%moss cover; litter=%litter cover; wood=%downed wood cover; feces=%feces cover; canopy=%canopy cover; can/hi=%high canopy cover; can/low=%low canopy cover; can/med=%medium canopy cover; roots=root biomass in g/m2 in top 10 cm of soil; live=standing live (green) crop in g/m2

Table 31. Cont.

| grid<br>unit | *dead | litter w | depth surf- | soil temp | infl. rt. | BD                | water | soil res                            | mammals |
|--------------|-------|----------|-------------|-----------|-----------|-------------------|-------|-------------------------------------|---------|
|              | g.    | g.       | cm          | C°        | min.      | g/cm <sup>3</sup> | %     | gCO <sub>2</sub> /m <sup>2</sup> /d | #       |
| 1            | 121.3 | 94.67    | 50          | 10.7      | 32.47     | 1.31              | 0.10  |                                     | 3       |
| 2            | 22.4  | 78.53    | 50          | 14.6      | 19.69     | 1.09              | 0.11  | 539.72                              | 1       |
| 3            | 256.3 | 218.15   | 50          | 9.6       | 27.10     | 1.30              | 0.10  | 1436.32                             | 1       |
| 4            | 47.8  | 147.81   | 28          | 10.1      | 1.17      | 0.85              | 0.42  | 687.81                              | 2       |
| 5            | 0.0   | 99.89    | 0           | 9.9       | 15.67     | 1.13              | 0.14  | 142.17                              | 1       |
| 6            | 0.0   | 78.35    | 37          | 9.8       | 33.17     | 1.18              | 0.16  | 3126.07                             | 0       |
| 7            | 4.5   | 97.81    | 49          | 14.2      | 40.50     | 1.26              | 0.07  | 0.10                                | 1       |
| 8            | 0.0   | 20.44    | 50          |           | 44.83     | 1.32              | 0.16  | 1476.90                             | 2       |
| 9            | 22.4  | 87.83    | 6           | 13.1      | 3.67      | 0.86              | 0.16  | 1769.37                             | 0       |
| 10           | 26.4  | 111.41   | 7           | 16.9      | 12.78     | 0.97              | 0.19  | 399.49                              | 1       |
| 11           | 40.9  | 238.30   | 9           | 16.3      | 17.44     | 1.40              | 0.08  | 2882.68                             | 4       |
| 12           | 9.4   | 197.59   | 9           | 11.1      | 11.16     | 0.82              | 0.33  | 2932.77                             | 0       |
| 13           | 15.5  | 93.57    | 7           | 17.7      | 27.29     | 1.41              | 0.06  |                                     | 3       |
| 14           | 12.9  | 67.21    | 44          | 17.5      | 14.14     | 1.26              | 0.22  | 687.81                              | 0       |
| 15           | 2.1   | 6.83     |             | 14.5      | 3.22      | 1.81              | 0.26  | 504.76                              | 0       |
| 16           | 7.7   | 44.89    | 37          |           | 31.33     | 1.19              | 0.07  | 728.87                              | 4       |
| 17           | 11.4  | 42.66    | 26          |           | 31.44     | 1.19              | 0.29  | 1442.68                             | 1       |
| 18           | 10.1  | 50.81    | 50          | 16.1      | 26.56     | 0.72              | 0.57  | 2438.70                             | 1       |
| 19           | 27.4  | 34.96    | 11          | 11.2      | 24.60     | 0.84              | 0.58  | 3126.07                             | 0       |
| 20           | 6.5   | 22.67    | 39          |           | 37.57     | 1.45              | 0.08  | 876.12                              | 2       |
| 21           | 6.6   | 65.16    | 48          |           |           | 1.50              | 0.06  | 437.33                              | 2       |
| 22           | 1.9   | 92.41    | 6           |           | 17.63     | 1.19              | 0.16  | 789.89                              | 4       |
| 23           | 4.2   | 175.64   | 7           |           | 10.94     | 0.91              | 0.23  | 98.00                               | 0       |
| 24           | 0.0   | 0.00     | 37          | 18.5      | 10.00     | 1.10              | 0.13  |                                     | 1       |
| 25           | 0.0   | 150.10   | 25          | 22.8      | 32.67     | 1.14              | 0.06  | 664.54                              | 2       |
| 26           | 35.9  | 63.83    | 10          | 19.5      | 11.11     | 1.27              | 0.09  | 1178.02                             | 0       |
| 27           | 90.5  | 107.52   | 39          | 18.2      | 11.11     | 1.15              | 0.06  | 667.09                              | 1       |
| 28           | 72.8  | 41.98    | 43          | 20.6      | 16.33     | 1.14              | 0.12  | 246.96                              | 0       |
| 29           | 0.0   | 92.15    | 50          | 16.3      | 51.00     | 1.46              | 0.19  | 1767.75                             | 0       |
| 30           | 0.0   | 0.00     | 50          | 16.6      | 44.67     | 1.46              | 0.18  | 688.87                              | 0       |
| 31           | 174.0 | 82.40    | 16          | 14.4      | 23.11     | 0.64              | 0.79  | 1756.88                             | 0       |
| 32           | 11.3  | 69.40    | 50          | 18.3      | 36.33     | 1.21              | 0.11  | 453.39                              | 1       |
| 33           | 5.8   | 131.89   | 42          | 21.6      | 25.56     | 1.68              | 0.04  | 169.47                              | 2       |
| 34           | 0.0   | 0.00     |             |           | 65.00     |                   |       | 0.00                                | 0       |
| 35           | 0.0   | 0.00     |             |           | 65.00     |                   |       | 0.00                                | 0       |

\*dead=standing dead crop in g/m<sup>2</sup>; litter w= litter biomass in g/m<sup>2</sup>; depth surf.=depth of soil surface horizon in cm; soil temp=soil temperature at 50 cm depth; infl. rt.= water infiltration rt. in minutes; BD=soil bulk density in g/cm<sup>3</sup>; water= %soil water by wt.; soil res= soil respiration in mg CO<sub>2</sub>/m<sup>2</sup>/24hrs.; mammals= # of mammal taxons

Table 31. Cont.

| grid<br>unit | arthropods<br># | K<br>ppm | EC<br>mmhos/cm | N<br>% | sand<br>% | silt<br>% | clay<br>% | OM<br>% | P<br>ppm | pH  | NO <sub>3</sub><br>ppm | plnt<br>morf div<br>index score |
|--------------|-----------------|----------|----------------|--------|-----------|-----------|-----------|---------|----------|-----|------------------------|---------------------------------|
| 1            | 3               | 528      | 0.2            | 0.108  | 14        | 64        | 22        | 1.84    | 9.8      | 8.5 | 2.1                    | 1.03                            |
| 2            | 2               | 710      | 0.25           | 0.171  | 34        | 42        | 24        | 3.04    | 8.4      | 8.7 | 1.5                    | 0.98                            |
| 3            | 1               | 282      | 0.12           | 0.087  | 32        | 49        | 19        | 1.41    | 5.9      | 8.7 | 1.3                    | 0.10                            |
| 4            | 0               | 15900    | 5.96           | 0.945  | 47        | 33        | 20        | 14.15   | 1348.2   | 9   | 252.7                  | 0.34                            |
| 5            | 1               | 486      | 0.13           | 0.088  | 34        | 40        | 26        | 1.21    | 18.8     | 8.7 | 8.4                    | 0.68                            |
| 6            | 0               | 564      | 0.12           | 0.095  | 34        | 32        | 34        | 1.29    | 31.5     | 8.7 | 2.1                    | 1.02                            |
| 7            | 1               | 1044     | 0.31           | 0.126  | 25        | 51        | 24        | 2.07    | 12.9     | 9.2 | 4.2                    | 2.03                            |
| 8            | 2               | 398      | 0.25           | 0.149  | 47        | 33        | 20        | 2.7     | 34.1     | 8.4 | 35.5                   | 0.46                            |
| 9            | 4               | 732      | 0.19           | 0.181  | 47        | 31        | 22        | 3.65    | 12.9     | 8.4 | 7.4                    | 0.00                            |
| 10           | 3               | 500      | 0.65           | 0.106  | 37        | 30        | 33        | 1.71    | 9.1      | 8.1 | 8.6                    | 0.64                            |
| 11           | 1               | 292      | 0.11           | 0.11   | 50        | 33        | 17        | 1.78    | 10.7     | 8.6 | 4.4                    | 0.20                            |
| 12           | 2               | 582      | 0.29           | 0.319  | 54        | 33        | 13        | 8.54    | 16.6     | 7.9 | 6.6                    | 1.72                            |
| 13           | 2               | 852      | 1.47           | 0.097  | 31        | 48        | 21        | 1.49    | 13.2     | 9.1 | 14.8                   | 1.81                            |
| 14           | 0               | 496      | 0.23           | 0.234  | 47        | 29        | 24        | 4.57    | 61.1     | 8.5 | 30.3                   | 1.07                            |
| 15           | 1               | 562      | 0.17           | 0.256  | 41        | 40        | 19        | 4.86    | 12.1     | 8.4 | 7.1                    | 1.26                            |
| 16           | 3               | 454      | 0.14           | 0.165  | 53        | 29        | 18        | 3.22    | 5.6      | 8.3 | 3.1                    | 0.84                            |
| 17           | 6               | 586      | 0.57           | 0.3    | 39        | 33        | 28        | 5.2     | 10.1     | 8.2 | 31.1                   | 1.30                            |
| 18           | 6               | 1224     | 2.63           | 0.604  | 39        | 41        | 20        | 10.93   | 44.1     | 8   | 18.2                   | 1.14                            |
| 19           | 1               | 678      | 0.67           | 0.539  | 25        | 47        | 28        | 6.46    | 81.4     | 7.8 | 96.7                   | 0.12                            |
| 20           | 2               | 208      | 0.09           | 0.099  | 42        | 36        | 22        | 1.59    | 5.3      | 8.5 | 1.4                    | 1.25                            |
| 21           | 1               | 444      | 0.13           | 0.14   | 18        | 59        | 23        | 1.9     | 10.3     | 8.5 | 2.5                    | 1.21                            |
| 22           | 4               | 616      | 0.2            | 0.31   | 16        | 58        | 26        | 5.97    | 14.5     | 8   | 23.4                   | 1.95                            |
| 23           | 6               | 552      | 0.3            | 0.439  | 25        | 50        | 25        | 10.44   | 24.3     | 8   | 12.7                   | 2.16                            |
| 24           | 1               | 1296     | 0.67           | 0.257  | 40        | 39        | 21        | 4.96    | 112.5    | 8.4 | 61.5                   | 1.84                            |
| 25           | 5               | 494      | 0.13           | 0.118  | 34        | 45        | 21        | 2.05    | 6.7      | 8.5 | 2.7                    | 1.03                            |
| 26           | 0               | 290      | 0.1            | 0.07   | 47        | 26        | 27        | 1       | 6.9      | 8.6 | 1.2                    | 0.09                            |
| 27           | 2               | 338      | 0.11           | 0.09   | 40        | 31        | 29        | 1.53    | 7.9      | 8.5 | 1                      | 0.99                            |
| 28           | 5               | 434      | 0.09           | 0.084  | 42        | 31        | 27        | 1.19    | 5.9      | 8.5 | 1.7                    | 0.94                            |
| 29           | 2               | 164      | 0.14           | 0.083  | 49        | 33        | 18        | 0.88    | 44.1     | 8.6 | 15                     | 0.07                            |
| 30           | 3               | 228      | 0.14           | 0.083  | 44        | 32        | 24        | 1.35    | 22.4     | 8.6 | 13.4                   | 0.00                            |
| 31           | 3               | 844      | 1.91           | 0.405  | 31        | 46        | 23        | 8.06    | 16.8     | 9   | 26.8                   | 1.15                            |
| 32           | 5               | 1284     | 0.45           | 0.228  | 24        | 41        | 35        | 4.59    | 11       | 8.9 | 2.4                    | 0.45                            |
| 33           | 2               | 506      | 0.14           | 0.061  | 54        | 31        | 15        | 0.81    | 25.2     | 8.7 | 4.8                    | 1.08                            |
| 34           | 0               |          |                |        |           |           |           |         |          |     |                        | 0.00                            |
| 35           | 1               |          |                |        |           |           |           |         |          |     |                        | 0.00                            |

\*arthropods=# macroarthropod taxons; K= soil potassium in ppm.;

EC= soil electrical conductivity in mmhos/cm 1 to 2.; N=total soil Kjeldahl nitrogen;

NO<sub>3</sub>= soil nitrate in ppm; plnt morph div= plant morphological diversity index score.

Table 31. Cont.

| grid | *SR | weeds | candiv      | NO <sub>3</sub> /N | live/litter | C/N   | ref  | changes |
|------|-----|-------|-------------|--------------------|-------------|-------|------|---------|
| unit |     |       |             |                    |             |       | EI   |         |
|      | #   | %     | index score |                    |             |       |      | #       |
| 1    | 8   | 2.0   | 0.00        | 0.0019             | 1.509       | 9.91  | 0.74 | 2       |
| 2    | 23  | 28.8  | 0.00        | 0.0009             | 1.269       | 10.34 | 0.57 | 0       |
| 3    | 8   | 0.2   | 0.00        | 0.0015             | 0.718       | 9.42  | 0.71 | 2       |
| 4    | 8   | 98.2  | 0.05        | 0.0267             | 0.596       | 8.71  | NC   | 1       |
| 5    | 4   | 18.1  | 0.00        | 0.0095             | 0.000       | 7.99  | 0.39 | 0       |
| 6    | 6   | 32.2  | 0.00        | 0.0022             | 0.686       | 7.89  | 0.50 | 0       |
| 7    | 24  | 9.0   | 0.08        | 0.0033             | 0.642       | 9.55  | 0.66 | 0       |
| 8    | 4   | 9.1   | 0.00        | 0.0233             | 4.847       | 10.54 | 0.35 | 1       |
| 9    | 8   | 0.0   | 0.00        | 0.0041             | 0.586       | 11.72 | 0.49 | 1       |
| 10   | 19  | 5.0   | 0.00        | 0.0080             | 0.305       | 9.38  | 0.63 | 1       |
| 11   | 18  | 7.2   | 0.00        | 0.0040             | 0.249       | 9.41  | 0.66 | 1       |
| 12   | 37  | 31.9  | 0.44        | 0.0021             | 0.118       | 15.56 | 1.00 | 1       |
| 13   | 18  | 31.6  | 0.11        | 0.0150             | 0.457       | 8.93  | 0.77 | 0       |
| 14   | 64  | 24.1  | 0.13        | 0.0129             | 0.049       | 11.35 | 0.60 | 0       |
| 15   | 69  | 30.5  | 0.10        | 0.0028             | 20.409      | 11.04 | 0.52 | 0       |
| 16   | 25  | 7.5   | 0.00        | 0.0019             | 0.388       | 11.35 | 0.52 | 0       |
| 17   | 25  | 46.9  | 0.17        | 0.0104             | 2.803       | 10.08 | 0.61 | 0       |
| 18   | 31  | 38.2  | 0.00        | 0.0030             | 4.361       | 10.52 | 0.58 | 0       |
| 19   | 11  | 49.2  | 0.00        | 0.0179             | 37.341      | 6.97  | 0.43 | 1       |
| 20   | 19  | 0.0   | 0.15        | 0.0014             | 0.530       | 9.34  | 1.00 | 0       |
| 21   | 6   | 9.1   | 0.00        | 0.0018             | 0.547       | 7.89  | 0.54 | 2       |
| 22   | 27  | 39.1  | 0.36        | 0.0075             | 0.222       | 11.20 | 0.75 | 0       |
| 23   | 32  | 38.2  | 0.39        | 0.0029             | 0.000       | 13.83 | 0.83 | 1       |
| 24   | 45  | 56.5  | 0.29        | 0.0239             |             | 11.22 | 0.62 | 0       |
| 25   | 15  | 12.0  | 0.00        | 0.0023             | 0.265       | 10.10 | 0.69 | 0       |
| 26   | 3   | 1.5   | 0.00        | 0.0017             | 0.518       | 8.31  | 0.51 | 1       |
| 27   | 3   | 0.0   | 0.00        | 0.0011             | 0.862       | 9.88  | 0.64 | 1       |
| 28   | 12  | 1.5   | 0.00        | 0.0020             | 0.972       | 8.24  | 0.63 | 1       |
| 29   | 4   | 0.5   | 0.00        | 0.0178             | 7.024       | 6.16  | 0.25 | 3       |
| 30   | 1   | 0.0   | 0.10        | 0.0159             |             | 9.46  | 0.44 | 2       |
| 31   | 44  | 45.7  | 0.00        | 0.0066             | 4.371       | 11.57 | 0.64 | 0       |
| 32   | 28  | 0.5   | 0.01        | 0.0011             | 1.189       | 11.70 | 0.55 | 1       |
| 33   | 9   | 28.4  | 0.00        | 0.0078             | 0.209       | 7.72  | 0.55 | 1       |
| 34   | 8   | 0.0   | 0.00        |                    |             |       | 0.07 | 0       |
| 35   | 3   | 100.0 | 0.00        |                    |             |       | 0.02 | 0       |

\*SR=plant species richness; weeds=%undesirable plant species;  
 candiv=plant canopy diversity index score; NO<sub>3</sub>/N=soil nitrate to total nitrogen ratio  
 C/N=soil organic carbon to nitrogen ratio; ref EI= referenced ecosystem integrity  
 changes= # of land use changes determined through aerial photo interpretation.

**Table 32.** Raw data and plot information for 1996 sample plots.

| grid<br>unit | cover<br>class | land use     | owner                 | Phone    |
|--------------|----------------|--------------|-----------------------|----------|
| 1            | 292            | CRP          | Stanley Kimm          | 285-6695 |
| 2            | 292            | CRP          | Mrs. Don Johnston     | 285-6629 |
| 3            | 32             | shrub range  | Don Scofield          | 285-6746 |
| 4            | 32             | shrub range  | Don Scofield          | 285-6746 |
| 5            | 32             | shrub range  | Don Scofield          | 285-6746 |
| 6            | 32             | shrub range  | George Kahrl          | 285-3651 |
| 7            | 32             | shrub range  | George Kahrl          | 285-3651 |
| 8            | 22             | irr wheat    | Robert Lane           | 285-6693 |
| 9            | 24             | irr alfalfa  | Robert Lane           | 285-6693 |
| 10           | 23             | up dry hay   | Robert Lane           | 285-6693 |
| 11           | 21             | crop fallow  | Dennis Rahn           | 285-6843 |
| 12           | 16             | low highway  | highway department    | 582-3250 |
| 13           | 21             | crop fallow  | Dennis Rahn           | 285-6843 |
| 14           | 23             | up dry hay   | David, Marie Hamilton | 285-6622 |
| 15           | 32             | shrub range  | George Kahrl          | 285-3651 |
| 16           | 14             | up highway   | highway department    | 582-3250 |
| 17           | 16             | low highway  | highway department    | 582-3250 |
| 18           | 292            | CRP          | Stanley Kimm          | 285-6695 |
| 19           | 33             | seeded range | George Kahrl          | 285-3651 |
| 20           | 292            | CRP          | George Kahrl          | 285-3651 |
| 21           | 292            | CRP          | George Kahrl          | 285-3651 |
| 22           | 33             | seeded range | George Kahrl          | 285-3651 |
| 23           | 15             | comercial    | Dean Volkford         | 285-3614 |

Table 32. Cont.

| grid address<br>unit         | *X | Y  | date   | land form | BS | BV | rock |
|------------------------------|----|----|--------|-----------|----|----|------|
|                              |    |    |        |           | %  | %  | %    |
| 1 16 Bunny DR. TF            | 18 | 11 | 7-Jun  | 1         | 12 | 5  | 1    |
| 2 42 Wheatland Rd. TF        | 17 | 6  | 11-Jun | 1         | 18 | 2  | 0    |
| 3 RTE 1 box 246 TF           | 21 | 1  | 11-Jun | 1         | 24 | 3  | 0    |
| 4 RTE 1 box 246 TF           | 24 | 5  | 12-Jun | 1         | 8  | 2  | 0    |
| 5 RTE 1 box 246 TF           | 36 | 14 | 12-Jun | 1         | 13 | 1  | 0    |
| 6 box 62 willow Creek        | 12 | 29 | 13-Jun | 1         | 9  | 4  | 1    |
| 7 box 62 willow Creek        | 2  | 37 | 13-Jun | 1         | 30 | 3  | 1    |
| 8 Lane Rd. box 97 TF         | 26 | 20 | 14-Jun | 1         | 91 | 1  | 1    |
| 9 Lane Rd. box 97 TF         | 23 | 20 | 14-Jun | 1         | 63 | 4  | 0    |
| 10 Lane Rd. box 97 TF        | 25 | 20 | 18-Jun | 1         | 41 | 3  | 1    |
| 11 154 Wheatland Rd TF       | 1  | 9  | 18-Jun | 1         | 80 | 0  | 1    |
| 12 201 W Tamarack Rd Bozeman | 47 | 30 | 19-Jun | 0         | 31 | 3  | 1    |
| 13 154 Wheatland Rd TF       | 3  | 9  | 19-Jun | 1         | 96 | 1  | 1    |
| 14 10895 US Hwy 287 TF       | 14 | 32 | 21-Jun | 1         | 48 | 2  | 1    |
| 15 box 62 willow Creek       | 1  | 22 | 21-Jun | 1         | 43 | 3  | 1    |
| 16 201 W Tamarack Rd Bozeman | 1  | 18 | 26-Jun | 1         | 31 | 2  | 3    |
| 17 201 W Tamarack Rd Bozeman | 44 | 26 | 26-Jun | 0         | 1  | 2  | 1    |
| 18 16 Bunny DR. TF           | 12 | 14 | 27-Jun | 1         | 41 | 2  | 2    |
| 19 box 62 willow Creek       | 10 | 28 | 27-Jun | 1         | 24 | 2  | 0    |
| 20 box 62 willow Creek       | 11 | 37 | 28-Jun | 1         | 36 | 2  | 4    |
| 21 box 62 willow Creek       | 7  | 39 | 2-Jul  | 1         | 46 | 2  | 0    |
| 22 box 62 willow Creek       | 6  | 30 | 2-Jul  | 1         | 43 | 2  | 1    |
| 23 10770 US Hwy 287 TF       | 20 | 18 | 3-Jul  | 1         | 6  | 0  | 93   |

\*X,Y= sample grid coordinates; land form, 0=valley bottom, 1=upland;  
 BS=%bare soil; BV=%basal vegetation cover; rock=%rock or pavement  
 cover;

Table 32. Cont.

| grid<br>unit | *moss | litter | wood | feces | canopy | can/hi | can/low | can/med | roots  | live   |
|--------------|-------|--------|------|-------|--------|--------|---------|---------|--------|--------|
|              | %     | %      | %    | %     | %      | %      | %       | %       | g.     | g.     |
| 1            | 1     | 62     | 0    | 0     | 56     | 0      | 56      | 0       | 536.45 | 142.43 |
| 2            | 47    | 28     | 0    | 0     | 30     | 0      | 30      | 0       | 246.21 | 73.57  |
| 3            | 3     | 32     | 1    | 2     | 19     | 0      | 19      | 0       | 505.75 | 81.22  |
| 4            | 4     | 21     | 0    | 0     | 16     | 0      | 16      | 0       | 620.03 | 50.41  |
| 5            | 4     | 24     | 0    | 0     | 18     | 0      | 18      | 0       | 541.23 | 79.04  |
| 6            | 14    | 24     | 0    | 1     | 41     | 0      | 40      | 0       | 536.28 | 36.02  |
| 7            | 34    | 33     | 0    | 0     | 33     | 0      | 33      | 0       | 268.14 | 32.46  |
| 8            | 0     | 7      | 0    | 0     | 10     | 0      | 10      | 0       | 385.58 | 36.02  |
| 9            | 0     | 36     | 0    | 0     | 97     | 0      | 97      | 2       | 44.57  | 173.58 |
| 10           | 0     | 39     | 0    | 1     | 19     | 0      | 19      | 0       | 577.31 | 234.22 |
| 11           | 0     | 19     | 0    | 0     | 1      | 0      | 1       | 0       | 55.89  | 0.00   |
| 12           | 0     | 67     | 0    | 0     | 29     | 0      | 29      | 0       | 510.81 | 81.07  |
| 13           | 0     | 2      | 0    | 0     | 10     | 0      | 10      | 0       | 375.68 | 34.09  |
| 14           | 18    | 37     | 0    | 0     | 14     | 0      | 14      | 0       | 348.08 | 94.56  |
| 15           | 27    | 33     | 1    | 0     | 21     | 0      | 17      | 4       | 625.42 | 56.32  |
| 16           | 27    | 49     | 0    | 0     | 21     | 0      | 20      | 0       | 604.88 | 41.45  |
| 17           | 23    | 95     | 0    | 0     | 16     | 0      | 16      | 0       | 488.87 | 147.13 |
| 18           | 8     | 50     | 0    | 0     | 22     | 0      | 20      | 0       | 505.15 | 72.93  |
| 19           | 34    | 48     | 0    | 0     | 11     | 0      | 11      | 0       | 638.86 | 49.74  |
| 20           | 14    | 45     | 0    | 0     | 21     | 0      | 20      | 0       | 510.10 | 73.98  |
| 21           | 25    | 40     | 0    | 0     | 24     | 0      | 24      | 0       | 529.20 | 530.54 |
| 22           | 9     | 50     | 0    | 1     | 15     | 0      | 15      | 0       | 544.06 | 101.05 |
| 23           | 0     | 1      | 0    | 0     | 0      | 0      | 0       | 0       | 0.00   | 0.00   |

\*moss=%moss cover; litter=%litter cover; wood=%downed wood cover;  
feces=%feces cover; canopy=%canopy cover; can/hi=%high canopy cover;  
can/low=%low canopy cover; can/med=%medium canopy cover;  
roots=root biomass in g/m<sup>2</sup> in top 10 cm of soil; live=standing live (green) crop in g/m<sup>2</sup>.

Table 32. Cont.

| grid<br>unit | *dead | litter w | infl. rt. | BD                | water | soil res                            | mammals | arthropods |
|--------------|-------|----------|-----------|-------------------|-------|-------------------------------------|---------|------------|
|              | g.    | g.       | min.      | g/cm <sup>3</sup> | %     | gCO <sub>2</sub> /m <sup>2</sup> /d | #       | #          |
| 1            | 216.3 | 196.0    | 31.33     | 1.26              | 12    | 468.57                              | 0       | 6          |
| 2            | 219.6 | 147.2    | 13.33     | 1.19              | 06    | 943.76                              | 0       | 5          |
| 3            | 86.4  | 118.0    | 34.78     | 1.30              | 05    | 1174.13                             | 1       | 15         |
| 4            | 115.6 | 109.6    | 27.78     | 1.40              | 05    | 1464.97                             | 2       | 8          |
| 5            | 87.1  | 63.4     | 23.44     | 1.33              | 04    | 852.49                              | 7       | 8          |
| 6            | 10.6  | 16.7     | 33.75     | 1.28              | 04    | 1516.93                             | 5       | 9          |
| 7            | 27.9  | 76.2     | 21.89     | 1.39              | 06    | 64.26                               | 1       | 11         |
| 8            | 0.0   | 101.7    | 26.33     | 1.41              | 08    | 0.00                                | 2       | 8          |
| 9            | 0.0   | 136.0    | 56.00     | 1.74              | 01    | 1360.72                             | 3       | 11         |
| 10           | 17.6  | 195.7    | 52.33     | 1.64              | 04    | 284.15                              | 3       | 4          |
| 11           | 0.0   | 253.3    | 3.47      | 1.45              | 10    | 124.98                              | 0       | 4          |
| 12           | 8.4   | 59.3     | 21.50     | 1.32              |       | 1032.15                             | 1       | 9          |
| 13           | 23.4  | 80.5     | 30.44     | 1.40              | 11    | 0.00                                | 0       | 5          |
| 14           | 31.9  | 191.1    | 20.33     | 1.34              | 03    | 1873.66                             | 2       | 5          |
| 15           | 24.7  | 82.0     | 26.89     | 1.47              | 03    | 2439.38                             | 3       | 7          |
| 16           | 30.8  | 43.1     | 36.33     | 0.99              | 17    | 854.36                              | 1       | 11         |
| 17           | 37.7  | 293.9    | 3.64      | 1.06              |       | 530.43                              | 2       | 4          |
| 18           | 84.4  | 124.4    | 32.78     | 1.17              | 04    | 1633.68                             | 1       | 8          |
| 19           | 52.5  | 124.4    | 31.33     | 1.25              | 07    | 917.46                              | 3       | 4          |
| 20           | 63.6  | 72.9     | 16.56     | 1.12              | 10    | 311.29                              | 1       | 14         |
| 21           | 928.4 | 357.5    | 18.44     | 1.11              | 07    | 477.44                              | 2       | 16         |
| 22           | 79.8  | 209.5    | 25.89     | 1.35              | 06    | 20.37                               | 4       | 6          |
| 23           | 0.0   | 0.0      | 65.00     |                   |       | 0.00                                | 0       | 0          |

\*dead=standing dead crop in g/m<sup>2</sup>; litter w= litter biomass in g/m<sup>2</sup>;  
 infl. rt.= water infiltration rt. in minutes; BD=soil bulk density in g/cm<sup>3</sup>;  
 water= %soil water by wt.; soil res= soil respiration in mg CO<sub>2</sub>/m<sup>2</sup>/24hrs.;  
 mammals= # of mammal taxons; arthropods=# macroarthropod taxons;  
 arthropods=# macroarthropod taxons.

Table 32. Cont.

| grid<br>unit | *K   | EC       | N     | OM   | P     | pH   | NO3   | plnt morf<br>div | SR | weeds | candiv      |
|--------------|------|----------|-------|------|-------|------|-------|------------------|----|-------|-------------|
|              | ppm  | mmhos/cm | %     | %    | ppm   |      | ppm   | index score      | #  | %     | index score |
| 1            | 298  | 0.12     | 0.083 | 1.48 | 10.50 | 8.30 | 5.40  | 1.02             | 7  | 0.06  | 0.00        |
| 2            | 582  | 0.14     | 0.099 | 1.63 | 8.20  | 8.20 | 3.00  | 0.46             | 9  | 0.79  | 0.00        |
| 3            | 1348 | 0.36     | 0.141 | 2.79 | 17.10 | 8.80 | 3.90  | 1.78             | 20 | 0.08  | 0.00        |
| 4            | 886  | 0.25     | 0.151 | 2.82 | 9.50  | 8.40 | 0.70  | 1.91             | 29 | 0.53  | 0.00        |
| 5            | 806  | 0.19     | 0.124 | 2.48 | 15.30 | 8.40 | 0.30  | 1.76             | 18 | 0.53  | 0.07        |
| 6            | 360  | 0.24     | 0.142 | 2.55 | 7.40  | 7.80 | 0.50  | 0.85             | 32 | 0.85  | 0.03        |
| 7            | 320  | 0.24     | 0.142 | 2.50 | 6.20  | 7.70 | 0.40  | 0.75             | 31 | 0.27  | 0.00        |
| 8            | 208  | 0.29     | 0.098 | 1.76 | 51.40 | 8.00 | 25.20 | 0.00             | 2  | 0.00  | 0.00        |
| 9            | 192  | 0.26     | 0.098 | 1.57 | 30.80 | 8.00 | 33.70 | 0.11             | 7  | 0.52  | 0.15        |
| 10           | 376  | 0.20     | 0.088 | 1.41 | 31.40 | 8.00 | 2.90  | 0.09             | 4  | 0.11  | 0.00        |
| 11           | 384  | 0.27     | 0.090 | 1.32 | 32.40 | 8.20 | 4.20  | 0.00             | 1  | 0.00  | 0.00        |
| 12           | 558  | 0.91     | 0.164 | 3.08 | 12.60 | 7.70 | 3.00  | 0.72             | 26 | 0.24  | 0.00        |
| 13           | 528  | 0.29     | 0.089 | 1.51 | 17.90 | 7.70 | 32.20 | 0.00             | 1  | 0.00  | 0.00        |
| 14           | 350  | 0.15     | 0.125 | 1.94 | 6.00  | 8.10 | 0.90  | 1.05             | 10 | 0.00  | 0.00        |
| 15           | 242  | 0.10     | 0.106 | 1.72 | 3.80  | 8.30 | 0.60  | 1.49             | 21 | 0.57  | 0.30        |
| 16           | 330  | 0.14     | 0.075 | 1.82 | 2.60  | 8.00 | 2.10  | 1.52             | 20 | 18.57 | 0.18        |
| 17           | 294  | 0.17     | 0.187 | 4.49 | 13.20 | 8.00 | 4.80  | 0.03             | 6  | 64.83 | 0.00        |
| 18           | 332  | 0.16     | 0.087 | 1.33 | 6.30  | 8.00 | 6.20  | 1.10             | 12 | 2.11  | 0.00        |
| 19           | 282  | 0.16     | 0.145 | 2.46 | 5.60  | 8.10 | 6.80  | 1.19             | 10 | 5.81  | 0.00        |
| 20           | 358  | 0.11     | 0.135 | 2.38 | 7.60  | 8.20 | 1.60  | 1.54             | 27 | 8.04  | 0.00        |
| 21           | 456  | 0.14     | 0.120 | 2.35 | 10.20 | 8.20 | 1.30  | 1.06             | 10 | 1.45  | 0.00        |
| 22           | 598  | 0.16     | 0.120 | 2.07 | 11.60 | 8.20 | 1.90  | 1.11             | 6  | 1.69  | 0.00        |
| 23           | 158  | 1.19     | 0.027 | 0.46 | 6.60  | 8.20 | 15.60 | 0.00             | 2  | 0.00  | 0.00        |

\*K= soil potassium in ppm.; EC= soil electrical conductivity in mmhos/cm 1 to 2.;  
 %N=total soil Kjeldahl nitrogen; %OM=%soil organic matter;  
 P=soil Olsen phosphorus in ppm; pH= soil pH;NO3= soil nitrate in ppm;  
 plnt morf div= plant morphological diversity index score; SR=plant species richness;  
 weeds=%undesirable plant species; candiv=plant canopy diversity index score.

Table 32. Cont.

| grid | *NO <sub>3</sub> /N | live/litter | C/N  | bug net | ref ei             | changes |
|------|---------------------|-------------|------|---------|--------------------|---------|
| unit |                     |             |      |         |                    |         |
|      |                     |             |      | #       | index<br>score 0-1 |         |
| 1    | 0.0065              | 0.73        | 5.94 | 23      | 0.63               | 1       |
| 2    | 0.0030              | 0.50        | 5.49 | 18      | 0.68               | 1       |
| 3    | 0.0028              | 0.69        | 6.60 | 36      | 0.62               | 0       |
| 4    | 0.0005              | 0.46        | 6.23 | 12      | 0.71               | 0       |
| 5    | 0.0002              | 1.25        | 6.67 | 27      | 0.64               | 0       |
| 6    | 0.0004              | 2.15        | 5.99 | 24      | 0.64               | 0       |
| 7    | 0.0003              | 0.43        | 5.87 |         | 0.68               | 0       |
| 8    | 0.0257              | 0.35        | 5.99 | 29      | 0.57               | 1       |
| 9    | 0.0344              | 1.28        | 5.34 | 36      | 0.55               | 1       |
| 10   | 0.0033              | 1.20        | 5.34 | 5       | 0.65               | 1       |
| 11   | 0.0047              | 0.00        | 4.89 | 2       | 0.54               | 0       |
| 12   | 0.0018              | 2.91        | 6.26 |         | 0.49               | 1       |
| 13   | 0.0362              | 0.42        | 5.66 | 17      | 0.54               | 0       |
| 14   | 0.0007              | 0.49        | 5.17 | 20      | 0.75               | 0       |
| 15   | 0.0006              | 0.69        | 5.41 | 8       | 1.00               | 0       |
| 16   | 0.0028              | 0.96        | 8.09 | 35      | 0.71               | 1       |
| 17   | 0.0026              | 0.43        | 8.00 |         | 0.47               | 1       |
| 18   | 0.0071              | 0.59        | 5.10 | 15      | 0.73               | 2       |
| 19   | 0.0047              | 0.40        | 5.66 | 20      | 0.72               | 2       |
| 20   | 0.0012              | 1.01        | 5.88 | 40      | 0.69               | 1       |
| 21   | 0.0011              | 1.48        | 6.53 | 24      | 0.62               | 2       |
| 22   | 0.0016              | 0.48        | 5.75 | 8       | 0.71               | 2       |
| 23   | 0.0578              |             | 5.68 | 0       | 0.36               | 4       |

\*NO<sub>3</sub>/N=soil nitrate to total nitrogen ratio; live/litter=standing live crop/litter biomass ratio;  
 C/N=soil organic carbon to nitrogen ratio; bug net= # of arthropod taxons in sweep net;  
 ref EI= referenced ecosystem integrity index score;  
 changes= # of land use changes determined through aerial photo interpretation.

**APPENDIX B**

**CHAPTER 2 TABLES**

**Table 33.** Raw data from the 1995 visually estimated variable approach to measure rangeland health. Cover is scored as a percentage, each other variable is scored from 0-5.

| Plot | Land use               | Cover | Pedestalling | Rill-sheet erosion | Soil crusting | Desirable plants |
|------|------------------------|-------|--------------|--------------------|---------------|------------------|
|      |                        | %     | 0-5          | 0-5                | 0-5           | 0-5              |
| 1    | CRP                    | 93    | 5.0          | 5.0                | 2.4           | 5.0              |
| 2    | ungrazed bottom        | 62    | 4.5          | 5.0                | 3.5           | 4.8              |
| 3    | CRP                    | 41    | 4.5          | 5.0                | 1.5           | 4.8              |
| 4    | abon indust            | 51    | 4.9          | 5.0                | 4.5           | 0.2              |
| 5    | drycrop/fallow         | 8     | 5.0          | 5.0                | 4.6           | 4.7              |
| 6    | drycrop/fallow         | 43    | 5.0          | 5.0                | 3.3           | 3.1              |
| 7    | shrub range            | 60    | 4.0          | 4.1                | 4.4           | 4.1              |
| 8    | irr wheat              | 35    | 5.0          | 4.2                | 5.0           | 4.0              |
| 9    | valley bottom roadside | 87    | 4.5          | 4.9                | 2.4           | 1.1              |
| 10   | upland roadside        | 98    | 5.0          | 5.0                | 5.0           | 5.0              |
| 11   | upland roadside        | 71    | 4.5          | 4.5                | 4.8           | 4.8              |
| 12   | forested riparian      | 81    | 5.0          | 5.0                | 5.0           | 1.4              |
| 13   | shrub range            | 39    | 2.9          | 2.3                | 1.9           | 0.0              |
| 14   | residential            | 59    | 4.5          | 4.5                | 4.5           | 0.0              |
| 16   | grazed bottom          | 72    | 4.8          | 4.8                | 3.6           | 4.9              |
| 17   | non forest ripar.      | 77    | 5.0          | 5.0                | 5.0           | 4.5              |
| 18   | non forest ripar.      | 99    | 5.0          | 5.0                | 5.0           | 0.0              |
| 20   | shrub range            | 49    | 3.4          | 4.0                | 2.9           | 5.0              |
| 21   | seeded range           | 29    | 3.4          | 4.8                | 2.9           | 4.4              |
| 22   | forested riparian      | 96    | 5.0          | 5.0                | 5.0           | 0.0              |
| 23   | forested riparian      | 100   | 5.0          | 5.0                | 5.0           | 0.0              |
| 25   | upland hayfield        | 55    | 4.2          | 4.4                | 3.1           | 2.9              |
| 26   | CRP                    | 44    | 5.0          | 5.0                | 2.9           | 5.0              |
| 27   | CRP                    | 63    | 4.8          | 5.0                | 2.7           | 5.0              |
| 28   | CRP                    | 23    | 2.5          | 2.3                | 2.1           | 2.4              |
| 31   | non forest ripar.      | 99    | 5.0          | 5.0                | 5.0           | 3.6              |
| 32   | grazed bottom          | 81    | 4.8          | 4.8                | 4.8           | 4.6              |
| 33   | Upland hayfield        | 48    | 3.9          | 5.0                | 4.4           | 4.7              |

Table 33. Cont.

| Plot | Age class<br>distribution | Plant<br>vigor | Germination<br>sites | Litter<br>breakdown | Litter<br>abundance | Plant spacing |
|------|---------------------------|----------------|----------------------|---------------------|---------------------|---------------|
|      | 0-5                       | 0-5            | 0-5                  | 0-5                 | 0-5                 | 0-5           |
| 1    | 1.9                       | 2.7            | 2.0                  | 1.4                 | 2.0                 | 0.2           |
| 2    | 2.8                       | 2.5            | 1.9                  | 2.1                 | 2.5                 | 1.7           |
| 3    | 2.75                      | 3.0            | 2.3                  | 1.0                 | 1.7                 | 0.9           |
| 4    | 1.7                       | 2.5            | 3.4                  | 1.7                 | 2.3                 | 1.4           |
| 5    | 5                         | 0.4            | 5.0                  | 5.0                 | 3.0                 | 0.7           |
| 6    | 5                         | 4.8            | 3.7                  | 3.1                 | 1.9                 | 2.9           |
| 7    | 4.2                       | 3.4            | 3.8                  | 3.0                 | 2.5                 | 2.9           |
| 8    | 5                         | 4.7            | 5.0                  | 4.7                 | 1.8                 | 4.0           |
| 9    | 2.1                       | 2.0            | 2.7                  | 2.0                 | 3.9                 | 3.3           |
| 10   | 5                         | 4.9            | 5.0                  | 2.0                 | 4.9                 | 4.6           |
| 11   | 4.7                       | 3.8            | 3.6                  | 1.9                 | 3.6                 | 2.4           |
| 12   | 4.1                       | 3.6            | 4.3                  | 3.9                 | 3.2                 | 3.1           |
| 13   | 2.2                       | 2.0            | 0.7                  | 1.0                 | 1.4                 | 1.4           |
| 14   | 2.7                       | 3.9            | 3.7                  | 2.5                 | 3.1                 | 4.3           |
| 16   | 3.15                      | 3.7            | 3.1                  | 2.0                 | 2.9                 | 3.1           |
| 17   | 3.7                       | 4.4            | 4.3                  | 2.3                 | 3.4                 | 1.5           |
| 18   | 5                         | 5.0            | 5.0                  | 4.0                 | 2.2                 | 4.9           |
| 20   | 2.85                      | 2.5            | 2.7                  | 2.0                 | 1.4                 | 2.1           |
| 21   | 1.5                       | 3.3            | 1.8                  | 2.0                 | 1.3                 | 1.2           |
| 22   | 4.1                       | 4.1            | 4.2                  | 3.5                 | 4.5                 | 3.8           |
| 23   | 3.5                       | 3.5            | 5.0                  | 3.1                 | 5.0                 | 3.2           |
| 25   | 2.55                      | 5.0            | 3.0                  | 3.0                 | 2.9                 | 2.1           |
| 26   | 1.4                       | 4.5            | 2.9                  | 2.0                 | 2.1                 | 1.2           |
| 27   | 2.1                       | 4.8            | 2.9                  | 2.0                 | 3.8                 | 2.1           |
| 28   | 1.3                       | 2.2            | 1.4                  | 1.0                 | 1.3                 | 0.9           |
| 31   | 4.6                       | 5.0            | 4.1                  | 3.1                 | 2.9                 | 4.0           |
| 32   | 3.8                       | 4.1            | 4.0                  | 2.0                 | 3.2                 | 3.1           |
| 33   | 3.15                      | 4.0            | 2.8                  | 2.0                 | 3.0                 | 1.6           |

Table 33. cont.

| Plot | Plant species<br>diversity | Canopy<br>distribution | Canopy<br>abundance | Utilization |
|------|----------------------------|------------------------|---------------------|-------------|
|      | 0-5                        | 0-5                    | 0-5                 | 0-5         |
| 1    | 3.0                        | 2.1                    | 2.2                 | 1.5         |
| 2    | 1.9                        | 1.1                    | 1.1                 | 0.9         |
| 3    | 0.3                        | 1.0                    | 1.3                 | 0.0         |
| 4    | 1.0                        | 1.1                    | 2.4                 | 0.3         |
| 5    | 0.0                        | 0.0                    | 0.0                 | 0.0         |
| 6    | 1.7                        | 1.0                    | 2.0                 | 0.2         |
| 7    | 1.8                        | 1.2                    | 2.4                 | 3.4         |
| 8    | 1.0                        | 1.0                    | 1.8                 | 0.0         |
| 9    | 2.0                        | 1.0                    | 0.9                 | 0.0         |
| 10   | 1.0                        | 1.0                    | 2.8                 | 0.0         |
| 11   | 1.0                        | 1.0                    | 2.0                 | 2.3         |
| 12   | 2.0                        | 1.2                    | 2.8                 | 2.0         |
| 13   | 2.1                        | 0.9                    | 4.8                 | 0.0         |
| 14   | 1.4                        | 1.1                    | 3.4                 | 0.0         |
| 16   | 3.7                        | 1.0                    | 1.4                 | 3.8         |
| 17   | 1.1                        | 1.0                    | 2.7                 | 3.5         |
| 18   | 1.8                        | 1.0                    | 4.9                 | 0.0         |
| 20   | 1.4                        | 1.2                    | 1.2                 | 2.7         |
| 21   | 1.2                        | 1.1                    | 1.2                 | 1.8         |
| 22   | 2.5                        | 2.1                    | 3.3                 | 3.4         |
| 23   | 3.4                        | 2.6                    | 3.6                 | 1.8         |
| 25   | 1.0                        | 1.0                    | 1.0                 | 5.0         |
| 26   | 1.0                        | 1.0                    | 1.0                 | 0.0         |
| 27   | 1.0                        | 1.1                    | 2.4                 | 0.0         |
| 28   | 0.6                        | 0.5                    | 0.5                 | 0.0         |
| 31   | 2.6                        | 1.0                    | 3.2                 | 0.5         |
| 32   | 3.4                        | 1.0                    | 2.2                 | 2.5         |
| 33   | 1.1                        | 1.0                    | 1.0                 | 5.0         |

**Table 34.** Raw data from the 1996 visual estimate approach to monitoring rangeland health. Cover is scored as a percentage each other variable is scored from 0-5.

| Plot | Land use        | Time | Sampler | Cover | Pedestalling | Rill-sheet erosion | Soil crusting |
|------|-----------------|------|---------|-------|--------------|--------------------|---------------|
|      |                 | min. |         | %     | 0-5          | 0-5                | 0-5           |
| 1    | CRP             |      | aurora  | 56    | 4.5          | 4.0                | 3.0           |
| 1    | CRP             | 15   | chris   | 51    | 5.0          | 5.0                | 3.4           |
| 1    | CRP             |      | jen     | 78    | 5.0          | 5.0                | 3.3           |
| 2    | CRP             | 15   | aurora  | 23    | 3.1          | 3.3                | 1.9           |
| 2    | CRP             | 20   | chris   | 62    | 5.0          | 5.0                | 2.8           |
| 2    | CRP             | 18   | jen     | 90    | 5.0          | 5.0                | 2.3           |
| 3    | shrub range     | 25   | aurora  | 30    | 3.0          | 3.3                | 2.4           |
| 3    | shrub range     | 20   | chris   | 22    | 5.0          | 5.0                | 3.2           |
| 3    | shrub range     | 24   | jen     | 34    | 5.0          | 2.4                | 2.3           |
| 4    | shrub range     |      | aurora  | 32    | 3.1          | 2.7                | 2.2           |
| 4    | shrub range     | 20   | chris   | 18    | 5.0          | 5.0                | 4.5           |
| 4    | shrub range     |      | jen     | 20    | 5.0          | 2.8                | 3.2           |
| 5    | shrub range     | 25   | aurora  | 55    | 5.3          | 3.4                | 2.8           |
| 5    | shrub range     | 30   | chris   | 41    | 5.0          | 5.0                | 5.0           |
| 5    | shrub range     | 23   | jen     | 70    | 5.0          | 2.8                | 2.6           |
| 6    | shrub range     | 25   | aurora  | 86    | 2.8          | 3.5                | 1.5           |
| 6    | shrub range     | 24   | dave    | 84    | 5.0          | 5.0                | 1.3           |
| 6    | shrub range     | 28   | jen     | 92    | 5.0          | 2.4                | 1.8           |
| 7    | shrub range     | 37   | aurora  | 44    | 2.6          | 2.7                | 1.4           |
| 7    | shrub range     | 42   | chris   | 33    | 4.9          | 4.5                | 1.7           |
| 7    | shrub range     | 37   | dave    | 82    | 4.7          | 5.0                | 2.3           |
| 10   | upland hayfield | 25   | aurora  | 21    | 1.8          | 3.2                | 2.5           |
| 10   | upland hayfield | 15   | chris   | 10    | 5            | 5                  | 2.6           |
| 10   | upland hayfield | 22   | jen     | 58    | 5            | 5                  | 4.4           |

Table 34. Cont.

| Plot | Land use        | Time | Sampler | Cover | Pedestalling | Rill-sheet erosion | Soil crusting |
|------|-----------------|------|---------|-------|--------------|--------------------|---------------|
|      |                 |      |         | %     | 0-5          | 0-5                | 0-5           |
| 12   | low highway     | *    | aurora  | 87    | 5.0          | 5.0                | 5.0           |
| 12   | low highway     | *    | chris   | 86    | 5.0          | 5.0                | 5.0           |
| 12   | low highway     | *    | jen     | 72    | 5.0          | 4.7                | 5.0           |
| 14   | upland hayfield | 24   | aurora  | 74    | 3.6          | 4.0                | 2.5           |
| 14   | upland hayfield | *    | chris   | 16    | 5.0          | 5.0                | 4.1           |
| 14   | upland hayfield | 20   | jen     | 71    | 4.9          | 4.2                | 4.6           |
| 15   | shrub range     | 30   | aurora  | 32    | 3.0          | 2.9                | 2.3           |
| 15   | shrub range     | 30   | chris   | 16    | 5.0          | 3.7                | 2.3           |
| 15   | shrub range     | 15   | dave    | 44    | 4.0          | 4.8                | 1.9           |
| 18   | CRP             | 15   | aurora  | 45    | 2.2          | 3.0                | 1.8           |
| 18   | CRP             | 15   | chris   | 42    | 5.0          | 5.0                | 2.3           |
| 18   | CRP             | 15   | jen     | 92    | 5.0          | 5.0                | 2.0           |
| 19   | seeded range    | *    | aurora  | 86    | 3.6          | 3.2                | 1.5           |
| 19   | seeded range    | 15   | dave    | 59    | 4.4          | 5.0                | 1.9           |
| 19   | seeded range    | 36   | jen     | 64    | 5.0          | 3.6                | 1.4           |
| 20   | CRP             | 25   | aurora  | 39    | 3.4          | 3.0                | 1.5           |
| 20   | CRP             | 29   | chris   | 12    | 5.0          | 5.0                | 3.8           |
| 20   | CRP             | 29   | jen     | 86    | 5.0          | 2.4                | 2.1           |
| 21   | CRP             | 23   | aurora  | 66    | 4.6          | 3.4                | 2.1           |
| 21   | CRP             | 25   | chris   | 9     | 5.0          | 5.0                | 3.2           |
| 21   | CRP             | 35   | jen     | 76    | 5.0          | 2.8                | 1.5           |
| 22   | seeded range    | *    | arora   | 43    | 4.7          | 3.6                | 2.8           |
| 22   | seeded range    | *    | chris   | 70    | 5.0          | 5.0                | 5.0           |
| 22   | seeded range    | 15   | dave    | 55    | 5.0          | 5.0                | 3.6           |

Table 34. Cont.

| plot | Desirable<br>plants | Age class<br>distribution | Plant<br>vigor | Germination<br>sites | Litter<br>breakdown | Litter<br>abundance | Plant<br>spacing |
|------|---------------------|---------------------------|----------------|----------------------|---------------------|---------------------|------------------|
|      | 0-5                 | 0-5                       | 0-5            | 0-5                  | 0-5                 | 0-5                 | 0-5              |
| 1    | 5                   | 2.4                       | 1.8            | 2.1                  | 0.9                 | 2.2                 | 1.3              |
| 1    | 5                   | 2.4                       | 5.0            | 2.9                  | 2.5                 | 1.7                 | 2.0              |
| 1    | 5                   | 3.2                       | 4.9            | 2.9                  | 2.4                 | 3.3                 | 1.6              |
| 2    | 2.9                 | 1.5                       | 1.7            | 1.8                  | 0.8                 | 1.9                 | 1.9              |
| 2    | 5                   | 2.7                       | 5.0            | 2.7                  | 2.0                 | 1.3                 | 2.1              |
| 2    | 5                   | 2.1                       | 3.9            | 2.6                  | 2.0                 | 4.2                 | 3.6              |
| 3    | 4.8                 | 2.3                       | 1.8            | 1.8                  | 1.4                 | 1.3                 | 1.6              |
| 3    | 5                   | 3.0                       | 5.0            | 2.5                  | 2.0                 | 0.8                 | 2.5              |
| 3    | 4.8                 | 2.2                       | 4.8            | 1.8                  | 2.5                 | 1.4                 | 1.5              |
| 4    | 4.4                 | 2.2                       | 1.7            | 2.0                  | 1.7                 | 1.8                 | 2.2              |
| 4    | 3.05                | 3.0                       | 5.0            | 3.0                  | 2.3                 | 2.4                 | 2.0              |
| 4    | 5                   | 2.5                       | 4.5            | 1.7                  | 2.2                 | 1.5                 | 1.7              |
| 5    | 4.3                 | 1.3                       | 2.5            | 2.9                  | 1.4                 | 2.3                 | 2.1              |
| 5    | 4.5                 | 3.0                       | 5.0            | 4.8                  | 2.0                 | 1.7                 | 2.8              |
| 5    | 4.2                 | 2.0                       | 4.0            | 2.0                  | 2.3                 | 2.0                 | 1.9              |
| 6    | 5                   | 2.0                       | 3.1            | 2.6                  | 0.8                 | 1.4                 | 3.2              |
| 6    | 5                   | 1.3                       | 3.9            | 1.7                  | 0.3                 | 1.1                 | 3.6              |
| 6    | 5                   | 2.3                       | 4.2            | 2.5                  | 0.9                 | 1.3                 | 3.6              |
| 7    | 5                   | 1.4                       | 3.0            | 2.2                  | 1.6                 | 1.3                 | 2.4              |
| 7    | 5                   | 3.1                       | 4.1            | 1.6                  | 1.4                 | 1.1                 | 1.2              |
| 7    | 5                   | 2.0                       | 4.7            | 2.9                  | 2.5                 | 2.0                 | 2.8              |
| 10   | 3.8                 | 1.1                       | 0.4            | 1.8                  | 0.6                 | 1.3                 | 0.9              |
| 10   | 5                   | 3.0                       | 5.0            | 1.8                  | 2.5                 | 1.6                 | 0.8              |
| 10   | 4.6                 | 0.8                       | 4.8            | 2.0                  | 3.0                 | 2.9                 | 0.8              |

Table 34. Cont.

| plot | Desirable<br>plants | Age class<br>distribution | Plant<br>vigor | Germination<br>sites | Litter<br>breakdown | Litter<br>abundance | Plant<br>spacing |
|------|---------------------|---------------------------|----------------|----------------------|---------------------|---------------------|------------------|
|      | 0-5                 | 0-5                       | 0-5            | 0-5                  | 0-5                 | 0-5                 | 0-5              |
| 12   | 4.7                 | 4.0                       | 3.7            | 3.7                  | 2.5                 | 3.5                 | 3.5              |
| 12   | 5.0                 | 3.0                       | 5.0            | 4.7                  | 2.5                 | 4.0                 | 3.0              |
| 12   | 5.0                 | 3.7                       | 4.7            | 4.2                  | 2.2                 | 4.2                 | 3.7              |
| 14   | 5.0                 | 2.5                       | 2.1            | 2.1                  | 2.1                 | 2.4                 | 2.9              |
| 14   | 5.0                 | 3.0                       | 4.9            | 3                    | 2.5                 | 2.0                 | 2.0              |
| 14   | 5.0                 | 2.3                       | 4.0            | 3.4                  | 2.1                 | 3.6                 | 1.7              |
| 15   | 5.0                 | 1.7                       | 2.8            | 1.5                  | 0.6                 | 0.7                 | 1.3              |
| 15   | 5.0                 | 3.0                       | 4.7            | 2.3                  | 2.0                 | 0.7                 | 0.9              |
| 15   | 5.0                 | 1.5                       | 2.4            | 2.3                  | 2.1                 | 1.1                 | 1.1              |
| 18   | 5.0                 | 2.2                       | 2.2            | 1.6                  | 1.0                 | 1.8                 | 1.8              |
| 18   | 5.0                 | 3.0                       | 5.0            | 2.6                  | 2.0                 | 1.7                 | 1.5              |
| 18   | 5.0                 | 1.9                       | 4.2            | 2.2                  | 1.2                 | 3.8                 | 2.4              |
| 19   | 5.0                 | 3.0                       | 2.8            | 2.7                  | 1.8                 | 2.8                 | 3.0              |
| 19   | 5.0                 | 2.4                       | 3.3            | 2.7                  | 2.0                 | 2.2                 | 1.3              |
| 19   | 5.0                 | 2.2                       | 4.2            | 2.2                  | 1.3                 | 3.4                 | 2.7              |
| 20   | 3.4                 | 2.6                       | 2.8            | 2.2                  | 0.8                 | 1.5                 | 1.6              |
| 20   | 4.5                 | 2.9                       | 4.6            | 2.7                  | 2.0                 | 2.0                 | 2.6              |
| 20   | 2.8                 | 2.3                       | 4.2            | 2.5                  | 1.6                 | 3.6                 | 2.5              |
| 21   | 5.0                 | 1.6                       | 1.5            | 1.8                  | 0.9                 | 2.0                 | 2.2              |
| 21   | 5.0                 | 2.1                       | 4.3            | 3.1                  | 2.2                 | 2.0                 | 1.5              |
| 21   | 4.6                 | 2.1                       | 4.1            | 2                    | 1.7                 | 2.5                 | 1.8              |
| 22   | 5.0                 | 2.1                       | 3.2            | 2.6                  | 2.1                 | 5.1                 | 2.7              |
| 22   | 5.0                 | 1.7                       | 4.7            | 4.3                  | 2.5                 | 2.7                 | 2.1              |
| 22   | 5.0                 | 0.4                       | 3.2            | 3.2                  | 1.6                 | 2.6                 | 1.4              |

Table 34. Cont.

| plot | Plant species<br>diversity | Canopy<br>distribution | Canopy<br>abundance | Utilization |
|------|----------------------------|------------------------|---------------------|-------------|
|      | 0-5                        | 0-5                    | 0-5                 | 0-5         |
| 1    | 2                          | 1.0                    | 1.5                 | 0.0         |
| 1    | 2                          | 2.0                    | 2.5                 | 0.0         |
| 1    | 1.9                        | 1.0                    | 3.7                 | 1.0         |
| 2    | 1.6                        | 1.0                    | 1.3                 | 0.0         |
| 2    | 1.4                        | 1.6                    | 2.5                 | 0.0         |
| 2    | 1                          | 1.1                    | 4.0                 | 0.0         |
| 3    | 2                          | 1.2                    | 0.9                 | 0.4         |
| 3    | 1.6                        | 1.6                    | 1.7                 | 1.5         |
| 3    | 2.3                        | 2.4                    | 1.6                 | 0.2         |
| 4    | 2.4                        | 1.6                    | 1.3                 | 0.5         |
| 4    | 2.4                        | 2.1                    | 1.4                 | 1.0         |
| 4    | 2.4                        | 1.9                    | 0.1                 | 0.0         |
| 5    | 1.2                        | 1.6                    | 0.9                 | 0.0         |
| 5    | 1.65                       | 1.6                    | 2.7                 | 0.0         |
| 5    | 1.5                        | 1.5                    | 2.2                 | 0.0         |
| 6    | 2.2                        | 1.0                    | 0.6                 | 0.0         |
| 6    | 1.8                        | 1.1                    | 3.3                 | 0.0         |
| 6    | 1.6                        | 1.9                    | 3.6                 | 0.0         |
| 7    | 1.9                        | 2.0                    | 0.5                 | 0.2         |
| 7    | 1.7                        | 2.2                    | 1.4                 | 0.0         |
| 7    | 2                          | 2.1                    | 2.1                 | 0.1         |
| 10   | 0.8                        | 0.8                    | 0.4                 | 0.0         |
| 10   | 0.5                        | 0.8                    | 0.7                 | 0.1         |
| 10   | 1.1                        | 1.1                    | 1.4                 | 4.7         |

**Table 34.** Cont.

| plot | Plant species<br>diversity | Canopy<br>distribution | Canopy<br>abundance | Utilization |
|------|----------------------------|------------------------|---------------------|-------------|
| 12   | 1.3                        | 1.0                    | 1.1                 | 0.5         |
| 12   | 1.2                        | 1.6                    | 4.0                 | 0.0         |
| 12   | 1.0                        | 1.0                    | 3.7                 | 0.0         |
| 14   | 1.8                        | 1.0                    | 1.0                 | 0.0         |
| 14   | 2.0                        | 1.0                    | 1.3                 | 0.3         |
| 14   | 1.3                        | 0.1                    | 2.7                 | 0.0         |
| 15   | 2.1                        | 1.8                    | 0.5                 | 0.3         |
| 15   | 1.6                        | 1.8                    | 1.1                 | 0.2         |
| 15   | 1.9                        | 1.3                    | 1.0                 | 0.0         |
| 18   | 1.0                        | 1.0                    | 1.2                 | 0.0         |
| 18   | 0.5                        | 1.0                    | 2.9                 | 0.0         |
| 18   | 1.0                        | 1.2                    | 3.8                 | 0.0         |
| 19   | 2.3                        | 1.0                    | 0.9                 | 2.2         |
| 19   | 1.4                        | 1.1                    | 0.9                 | 2.6         |
| 19   | 2.2                        | 2.1                    | 2.8                 | 1.2         |
| 20   | 2.0                        | 1.0                    | 0.8                 | 0.1         |
| 20   | 1.9                        | 1.6                    | 2.4                 | 0.0         |
| 20   | 1.8                        | 1.4                    | 3.0                 | 0.8         |
| 21   | 2.0                        | 1.0                    | 1.7                 | 0.5         |
| 21   | 1.7                        | 1.2                    | 3.1                 | 0.4         |
| 21   | 1.7                        | 1.6                    | 2.5                 | 0.9         |
| 22   | 2.1                        | 1.0                    | 1.1                 | 4.1         |
| 22   | 1.7                        | 1.0                    | 3.1                 | 4.6         |
| 22   | 1.9                        | 1.0                    | 1.6                 | 3.9         |

**APPENDIX C**

**CHAPTER 3 TABLES**

**Table 35.** Averages of net radiation and environmental measurements taken at each land use site on each date.

| Plot                | Date    | Net radiation | Net radiation    |
|---------------------|---------|---------------|------------------|
|                     |         | millivolts    | w/m <sup>2</sup> |
| Alfalfa irr.        | 6/7/96  | 47.9          | 613.12           |
| Alfalfa irr.        | 7/26/96 | 42.3          | 542.08           |
| Alfalfa irr.        | 8/22/96 | 37.0          | 473.60           |
| Alfalfa irr.        | 9/29/96 | 27.1          | 346.88           |
| CRP                 | 6/7/96  | 49.9          | 639.36           |
| CRP                 | 7/26/96 | 44.4          | 568.96           |
| CRP                 | 8/22/96 | 39.1          | 500.48           |
| CRP                 | 9/29/96 | 26.9          | 344.96           |
| Fallow              | 6/7/96  | 39.0          | 499.20           |
| Fallow              | 7/26/96 | 38.0          | 487.04           |
| Fallow              | 8/22/96 | 31.2          | 400.00           |
| Fallow              | 9/29/96 | 26.3          | 337.28           |
| Hay field-non-irr.  | 6/7/96  | 43.2          | 552.96           |
| Hayfield non-irr.   | 7/26/96 | 32.2          | 412.80           |
| Hayfield non-irr.   | 8/22/96 | 26.5          | 339.84           |
| Hayfield non-irr.   | 9/29/96 | 19.6          | 250.88           |
| Range               | 7/26/96 | 36.8          | 471.68           |
| Range               | 6/10/96 | 44.3          | 567.04           |
| Range               | 8/22/96 | 36.8          | 471.04           |
| Range               | 9/29/96 | 28.9          | 369.92           |
| Parking Lot         | 6/7/96  | 40.8          | 522.24           |
| Parking Lot         | 8/22/96 | 37.2          | 476.80           |
| Parking Lot         | 9/29/96 | 26.1          | 334.72           |
| Parking Lot         | 7/26/96 | 30.9          | 396.16           |
| Wheatfield irr.     | 6/7/96  | 39.1          | 500.48           |
| Wheatfield irr.     | 7/26/96 | 45.8          | 586.88           |
| Wheatfield irr.     | 8/22/96 | 29.3          | 375.68           |
| Wheatfield irr.     | 9/29/96 | 21.1          | 270.72           |
| Wheatfield non-irr. | 6/7/96  | 40.5          | 518.40           |
| Wheatfield non-irr. | 7/26/96 | 41.7          | 533.76           |
| Wheatfield non-irr. | 8/22/96 | 26.9          | 344.96           |
| Wheatfield non-irr. | 9/29/96 | 25.1          | 321.28           |

Table 35. Cont.

| Plot                | Date    | Air temp. | Wind speed | Relative humidity | Soil temp. |
|---------------------|---------|-----------|------------|-------------------|------------|
|                     |         | C°        | m/sec      | %                 | C°         |
| Alfalfa irr.        | 6/7/96  | 27        | 1.5        | 55.0              | 24.4       |
| Alfalfa irr.        | 7/26/96 | 27        | 1.4        | 69.1              | 21.1       |
| Alfalfa irr.        | 8/22/96 | 22        | 0.2        | 41.1              | 23.1       |
| Alfalfa irr.        | 9/29/96 | 24        | 1.1        | 37.0              | 19.6       |
| CRP                 | 6/7/96  | 28        | 1.5        | 24.0              | 34.0       |
| CRP                 | 7/26/96 | 28        | 0.9        | 38.4              | 49.8       |
| CRP                 | 8/22/96 | 27        | 1.0        | 21.3              | 39.1       |
| CRP                 | 9/29/96 | 28        | 5.2        | 15.1              | 35.0       |
| Fallow              | 6/7/96  | 28        | 0.6        | 28.1              | 44.8       |
| Fallow              | 7/26/96 | 28        | 1.4        | 34.7              | 51.7       |
| Fallow              | 8/22/96 | 27        | 1.2        | 26.8              | 49.7       |
| Fallow              | 9/29/96 | 27        | 5.7        | 17.8              | 34.6       |
| Hay field-non-irr.  | 6/7/96  | 25        | 0.7        | 59.0              | 51.7       |
| Hayfield non-irr.   | 7/26/96 | 26        | 1.6        | 46.5              | 33.8       |
| Hayfield non-irr.   | 8/22/96 | 22        | 0.6        | 40.7              | 34.4       |
| Hayfield non-irr.   | 9/29/96 | 22        | 2.0        | 35.9              | 33.7       |
| Range               | 7/26/96 | 26        | 0.7        | 52.1              | 43.1       |
| Range               | 6/10/96 | 25        | 1.5        | 52.1              | 39.0       |
| Range               | 8/22/96 | 25        | 0.1        | 33.7              | 40.0       |
| Range               | 9/29/96 | 26        | 3.4        | 14.0              | 31.7       |
| Parking Lot         | 6/7/96  | 26        | 2.0        | 41.1              | 37.2       |
| Parking Lot         | 8/22/96 | 25        | 1.5        | 28.2              | 37.4       |
| Parking Lot         | 9/29/96 | 27        | 6.4        | 14.7              | 31.4       |
| Parking Lot         | 7/26/96 | 24        | 0.8        | 60.5              | 35.5       |
| Wheatfield irr.     | 6/7/96  | 26        | 1.1        | 56.0              | 32.7       |
| Wheatfield irr.     | 7/26/96 | 25        | 0.8        | 52.1              | 24.1       |
| Wheatfield irr.     | 8/22/96 | 21        | 1.3        | 59.6              | 28.5       |
| Wheatfield irr.     | 9/29/96 | 23        | 0.1        | 34.5              | 34.8       |
| Wheatfield non-irr. | 6/7/96  | 26        | 2.5        | 37.7              | 41.9       |
| Wheatfield non-irr. | 7/26/96 | 28        | 2.2        | 32.8              | 46.0       |
| Wheatfield non-irr. | 8/22/96 | 27        | 2.1        | 24.0              | 33.9       |
| Wheatfield non-irr. | 9/29/96 | 27        | 9.2        | 17.8              | 33.8       |

Table 35. Cont.

| Plot                | Date    | Time  | Veg. ht. | Soil H <sub>2</sub> O |
|---------------------|---------|-------|----------|-----------------------|
|                     |         |       | cm       | %                     |
| Alfalfa irr.        | 6/7/96  | 13:02 | 48       | 6                     |
| Alfalfa irr.        | 7/26/96 | 12:02 | 50       | 3                     |
| Alfalfa irr.        | 8/22/96 | 11:52 | 16.5     | 12                    |
| Alfalfa irr.        | 9/29/96 | 12:29 | 31       | 9                     |
| CRP                 | 6/7/96  | 14:15 | 50       | 1                     |
| CRP                 | 7/26/96 | 13:48 | 60       | 1                     |
| CRP                 | 8/22/96 | 13:16 | 59       | 1                     |
| CRP                 | 9/29/96 | 14:22 | 58.5     | 2                     |
| Fallow              | 6/7/96  | 13:45 | 0        | 2                     |
| Fallow              | 7/26/96 | 13:24 | 0        | 1                     |
| Fallow              | 8/22/96 | 13:42 | 0        | 1                     |
| Fallow              | 9/29/96 | 13:47 | 0        | 5                     |
| Hay field-non-irr.  | 6/7/96  | 12:10 | 37       | 1                     |
| Hayfield non-irr.   | 7/26/96 | 12:35 | 16.5     | 1                     |
| Hayfield non-irr.   | 8/22/96 | 11:38 | 15       | 1                     |
| Hayfield non-irr.   | 9/29/96 | 11:37 | 12       | 5                     |
| Range               | 7/26/96 | 11:32 | 44.5     | 1                     |
| Range               | 6/10/96 | 11:38 | 48       | 2                     |
| Range               | 8/22/96 | 12:20 | 77.5     | 1                     |
| Range               | 9/29/96 | 13:05 | 43       | 2                     |
| Parking Lot         | 6/7/96  | 11:40 | 0        | 2                     |
| Parking Lot         | 8/22/96 | 12:51 | 0        | 1                     |
| Parking Lot         | 9/29/96 | 14:32 | 0        | 1                     |
| Parking Lot.        | 7/26/96 | 10:56 | 0        | 1                     |
| Wheatfield irr.     | 6/7/96  | 12:30 | 22       | 3                     |
| Wheatfield irr.     | 7/26/96 | 12:15 | 62.5     | 3                     |
| Wheatfield irr.     | 8/22/96 | 11:20 | 55.5     | 1                     |
| Wheatfield irr.     | 9/29/96 | 12:06 | 13.5     | 2                     |
| Wheatfield non-irr. | 6/7/96  | 13:33 | 10       | 5                     |
| Wheatfield non-irr. | 7/26/96 | 13:05 | 54       | 1                     |
| Wheatfield non-irr. | 8/22/96 | 13:32 | 24       | 5                     |
| Wheatfield non-irr. | 9/29/96 | 13:38 | 6        | 9                     |

Table 35. Cont

| Plot                | Date    | Canopy cover | Plant canopy<br>volume          |
|---------------------|---------|--------------|---------------------------------|
|                     |         | %            | cm <sup>3</sup> /m <sup>2</sup> |
| Alfalfa irr.        | 6/7/96  | 97           | 4656                            |
| Alfalfa irr.        | 7/26/96 | 87           | 4375                            |
| Alfalfa irr.        | 8/22/96 | 52           | 866                             |
| Alfalfa irr.        | 9/29/96 | 91           | 2821                            |
| CRP                 | 6/7/96  | 56           | 2800                            |
| CRP                 | 7/26/96 | 18           | 1080                            |
| CRP                 | 8/22/96 | 30           | 1770                            |
| CRP                 | 9/29/96 | 32           | 1901                            |
| Fallow              | 6/7/96  | 0            | 0                               |
| Fallow              | 7/26/96 | 0            | 0                               |
| Fallow              | 8/22/96 | 0            | 0                               |
| Fallow              | 9/29/96 | 0            | 0                               |
| Hay field-non-irr.  | 6/7/96  | 19           | 703                             |
| Hayfield non-irr.   | 7/26/96 | 18           | 305                             |
| Hayfield non-irr.   | 8/22/96 | 32           | 487                             |
| Hayfield non-irr.   | 9/29/96 | 37           | 450                             |
| Range               | 7/26/96 | 38           | 1713                            |
| Range               | 6/10/96 | 41           | 1968                            |
| Range               | 8/22/96 | 70           | 5425                            |
| Range               | 9/29/96 | 30           | 1290                            |
| Parking Lot         | 6/7/96  | 0            | 0                               |
| Parking Lot         | 8/22/96 | 0            | 0                               |
| Parking Lot         | 9/29/96 | 0            | 0                               |
| Parking Lot         | 7/26/96 | 0            | 0                               |
| Wheatfield irr.     | 6/7/96  | 10           | 220                             |
| Wheatfield irr.     | 7/26/96 | 32           | 2031                            |
| Wheatfield irr.     | 8/22/96 | 35           | 1942                            |
| Wheatfield irr.     | 9/29/96 | 12           | 168                             |
| Wheatfield non-irr. | 6/7/96  | 10           | 100                             |
| Wheatfield non-irr. | 7/26/96 | 21           | 1161                            |
| Wheatfield non-irr. | 8/22/96 | 22           | 540                             |
| Wheatfield non-irr. | 9/29/96 | 3            | 21                              |

**Table 36.** Raw data from net radiation and environmental measurements taken at each site.

| Land use site       | Date    | Net rad.   | Net rad          | Air temp | Wind speed | Relative humidity | Soil temp. |
|---------------------|---------|------------|------------------|----------|------------|-------------------|------------|
|                     |         | millivolts | w/m <sup>2</sup> | C°       | m/sec      | %                 | C°         |
| Parking Lot         | 6/7/96  | 40.8       | 522.24           | 26       | 2          | 41.1              | 37.2       |
| Hay field-non-irr.  | 6/7/96  | 42.9       | 549.12           | 26       | 0.8        | 59.0              | 51.7       |
| Hay field-non-irr.  | 6/7/96  | 43.5       | 556.80           | 26       | 0.6        | 59.0              | 51.7       |
| Wheatfield irr.     | 6/7/96  | 40.4       | 517.12           | 26       | 1.7        | 56.0              | 32.7       |
| Wheatfield irr.     | 6/7/96  | 37.8       | 483.84           | 27       | 0.6        | 56.0              | 32.7       |
| Alfalfa irr.        | 6/7/96  | 48.1       | 615.68           | 27       | 1.3        | 55.0              | 24.4       |
| Alfalfa irr.        | 6/7/96  | 47.7       | 610.56           | 27       | 1.7        | 55.0              | 24.4       |
| Wheatfield non-irr. | 6/7/96  | 41.2       | 527.36           | 27       | 2.1        | 37.7              | 41.9       |
| Wheatfield non-irr. | 6/7/96  | 39.8       | 509.44           | 27       | 2.9        | 37.7              | 41.9       |
| Fallow              | 6/7/96  | 40.1       | 513.28           | 28       | 1.1        | 28.1              | 44.8       |
| Fallow              | 6/7/96  | 37.9       | 485.12           | 28       | 0.2        | 28.1              | 44.8       |
| CRP                 | 6/7/96  | 50.7       | 648.96           | 29       | 2.2        | 24.0              | 34.0       |
| CRP                 | 6/7/96  | 49.2       | 629.76           | 29       | 0.9        | 24.0              | 34.0       |
| Range               | 6/10/96 | 45.4       | 581.12           | 25       | 1.4        | 52.1              | 39.0       |
| Range               | 6/10/96 | 43.2       | 552.96           | 25       | 1.6        | 52.1              | 39.0       |
| Parking Lot.        | 7/26/96 | 30.1       | 385.28           | 24       | 0.0        | 60.5              | 34.4       |
| Parking Lot         | 7/26/96 | 31.8       | 407.04           | 24       | 1.7        | 60.5              | 36.6       |
| Range               | 7/26/96 | 35.5       | 454.40           | 26       | 0.2        | 52.1              | 51.6       |
| Range               | 7/26/96 | 38.2       | 488.96           | 26       | 1.2        | 52.1              | 34.6       |
| Alfalfa irr.        | 7/26/96 | 42.1       | 538.88           | 28       | 1.5        | 69.1              | 21.6       |
| Alfalfa irr.        | 7/26/96 | 42.6       | 545.28           | 27       | 1.4        | 69.1              | 20.6       |
| Wheatfield irr.     | 7/26/96 | 44.7       | 572.16           | 25       | 1.2        | 52.1              | 25.1       |
| Wheatfield irr.     | 7/26/96 | 47.0       | 601.60           | 25       | 0.5        | 52.1              | 23.0       |
| Hayfield non-irr.   | 7/26/96 | 32.7       | 418.56           | 26       | 2.0        | 46.5              | 35.2       |
| Hayfield non-irr.   | 7/26/96 | 31.8       | 407.04           | 27       | 1.3        | 46.5              | 32.3       |
| Wheatfield non-irr. | 7/26/96 | 40.9       | 523.52           | 28       | 2.5        | 32.8              | 53.1       |
| Wheatfield non-irr. | 7/26/96 | 42.5       | 544.00           | 28       | 2.0        | 32.8              | 38.9       |
| Fallow              | 7/26/96 | 37.4       | 478.72           | 28       | 1.5        | 34.7              | 52.0       |
| Fallow              | 7/26/96 | 38.7       | 495.36           | 29       | 1.4        | 34.7              | 51.3       |
| CRP                 | 7/26/96 | 45.0       | 576.00           | 30       | 1.2        | 38.4              | 49.5       |
| CRP                 | 7/26/96 | 43.9       | 561.92           | 27       | 0.6        | 38.4              | 50.1       |
| Wheatfield irr.     | 8/22/96 | 28.8       | 368.64           | 21       | 2.0        | 59.6              | 31.1       |
| Wheatfield irr.     | 8/22/96 | 29.9       | 382.72           | 22       | 0.7        | 59.6              | 25.8       |
| Hayfield non-irr.   | 8/22/96 | 26.6       | 340.48           | 22       | 0.5        | 40.7              | 34.7       |
| Hayfield non-irr.   | 8/22/96 | 26.5       | 339.20           | 22       | 0.7        | 40.7              | 34.1       |
| Alfalfa irr.        | 8/22/96 | 36.4       | 465.92           | 22       | 0.2        | 41.1              | 22.8       |
| Alfalfa irr.        | 8/22/96 | 37.6       | 481.28           | 22       | 0.3        | 41.1              | 23.4       |
| Range               | 8/22/96 | 36.3       | 464.64           | 25       | 0.0        | 33.7              | 47.9       |
| Range               | 8/22/96 | 37.3       | 477.44           | 25       | 0.2        | 33.7              | 32.1       |

Table 36. Cont.

| Plot                | Date    | Net<br>radiation | Netrad<br>w/m <sup>2</sup> | Air<br>temp | Wind<br>speed | Relative<br>humidity | Soil<br>temp. |
|---------------------|---------|------------------|----------------------------|-------------|---------------|----------------------|---------------|
|                     |         | millivolts       | w/m <sup>2</sup>           | C°          | m/sec         | %                    | C°            |
| Parking Lot         | 8/22/96 | 37.3             | 477.44                     | 25          | 1.3           | 28.2                 | 37.9          |
| Parking Lot         | 8/22/96 | 37.2             | 476.16                     | 25          | 1.8           | 28.2                 | 36.9          |
| CRP                 | 8/22/96 | 39.0             | 499.20                     | 27          | 1.8           | 21.3                 | 39.3          |
| CRP                 | 8/22/96 | 39.2             | 501.76                     | 27          | 0.3           | 21.3                 | 38.8          |
| Wheatfield non-irr. | 8/22/96 | 28.1             | 359.68                     | 27          | 1.9           | 24.0                 | 33.7          |
| Wheatfield non-irr. | 8/22/96 | 25.8             | 330.24                     | 27          | 2.3           | 24.0                 | 34.1          |
| Fallow              | 8/22/96 | 31.7             | 405.76                     | 27          | 1.6           | 26.8                 | 49.8          |
| Fallow              | 8/22/96 | 30.8             | 394.24                     | 27          | 0.9           | 26.8                 | 49.6          |
| Hayfield non-irr.   | 9/29/96 | 18.9             | 241.92                     | 22          | 2.1           | 35.9                 | 33.3          |
| Hayfield non-irr.   | 9/29/96 | 20.3             | 259.84                     | 22          | 1.9           | 35.9                 | 34.1          |
| Wheatfield irr.     | 9/29/96 | 22.0             | 281.60                     | 23          | 0.0           | 34.5                 | 36.0          |
| Wheatfield irr.     | 9/29/96 | 20.3             | 259.84                     | 23          | 0.3           | 34.5                 | 33.5          |
| Alfalfa irr.        | 9/29/96 | 27.1             | 346.88                     | 24          | 1.5           | 37.0                 | 18.5          |
| Alfalfa irr.        | 9/29/96 | 27.1             | 346.88                     | 24          | 0.7           | 37.0                 | 20.7          |
| Range               | 9/29/96 | 27.8             | 355.84                     | 26          | 3.1           | 14.0                 | 38.4          |
| Range               | 9/29/96 | 30.0             | 384.00                     | 26          | 3.7           | 14.0                 | 25.0          |
| Wheatfield non-irr. | 9/29/96 | 26.2             | 335.36                     | 27          | 11.4          | 17.8                 | 33.7          |
| Wheatfield non-irr. | 9/29/96 | 24.0             | 307.20                     | 27          | 7.0           | 17.8                 | 33.9          |
| Fallow              | 9/29/96 | 26.0             | 332.80                     | 27          | 4.2           | 17.8                 | 34.1          |
| Fallow              | 9/29/96 | 26.7             | 341.76                     | 27          | 7.2           | 17.8                 | 35.0          |
| CRP                 | 9/29/96 | 27.0             | 345.60                     | 28          | 4.6           | 15.1                 | 34.7          |
| CRP                 | 9/29/96 | 26.9             | 344.32                     | 28          | 5.9           | 15.1                 | 35.2          |
| Parking Lot         | 9/29/96 | 26.2             | 335.36                     | 28          | 5.7           | 14.7                 | 31.2          |
| Parking Lot         | 9/29/96 | 26.1             | 334.08                     | 27          | 7.2           | 14.7                 | 31.5          |

Table 36. Cont.

| Land use site       | Date    | Time     | Veg.<br>ht. | Soil<br>H <sub>2</sub> O | Cover |
|---------------------|---------|----------|-------------|--------------------------|-------|
|                     |         |          | cm          | %                        | %     |
| Parking Lot         | 6/7/96  | 11:40 AM | 0           | 2.1                      | 0     |
| Hay field-non-irr.  | 6/7/96  | 12:08 PM | 37          | 1.9                      | 19    |
| Hay field-non-irr.  | 6/7/96  | 12:13 PM | 37          | 1.9                      | 19    |
| Wheatfield irr.     | 6/7/96  | 12:25 PM | 22          | 3.5                      | 10    |
| Wheatfield irr.     | 6/7/96  | 12:36 PM | 22          | 3.5                      | 10    |
| Alfalfa irr.        | 6/7/96  | 1:00 PM  | 48          | 6.9                      | 97    |
| Alfalfa irr.        | 6/7/96  | 1:05 PM  | 48          | 6.9                      | 97    |
| Wheatfield non-irr. | 6/7/96  | 1:30 PM  | 10          | 5.5                      | 10    |
| Wheatfield non-irr. | 6/7/96  | 1:37 PM  | 10          | 5.5                      | 10    |
| Fallow              | 6/7/96  | 1:40 PM  | 0           | 2.2                      | 0     |
| Fallow              | 6/7/96  | 1:50 PM  | 0           | 2.2                      | 0     |
| CRP                 | 6/7/96  | 2:10 PM  | 50          | 1.2                      | 56    |
| CRP                 | 6/7/96  | 2:20 PM  | 50          | 1.2                      | 56    |
| Range               | 6/10/96 | 11:32 AM | 58          | 2.0                      | 41    |
| Range               | 6/10/96 | 11:45 AM | 38          | 2.0                      | 41    |
| Parking Lot.        | 7/26/96 | 10:53 AM | 0           | 0.3                      | 0     |
| Parking Lot.        | 7/26/96 | 11:00 AM | 0           | 0.3                      | 0     |
| Range               | 7/26/96 | 11:30 AM | 39          | 0.5                      | 35    |
| Range               | 7/26/96 | 11:35 AM | 50          | 0.5                      | 42    |
| Alfalfa irr.        | 7/26/96 | 12:00 PM | 49          | 3.5                      | 90    |
| Alfalfa irr.        | 7/26/96 | 12:05 PM | 51          | 3.5                      | 85    |
| Wheatfield irr.     | 7/26/96 | 12:10 PM | 55          | 3.0                      | 35    |
| Wheatfield irr.     | 7/26/96 | 12:20 PM | 70          | 3.0                      | 30    |
| Hayfield non-irr.   | 7/26/96 | 12:31 PM | 16          | 0.5                      | 18    |
| Hayfield non-irr.   | 7/26/96 | 12:40 PM | 17          | 0.5                      | 19    |
| Wheatfield non-irr. | 7/26/96 | 1:00 PM  | 50          | 0.2                      | 17    |
| Wheatfield non-irr. | 7/26/96 | 1:11 PM  | 58          | 0.2                      | 26    |
| Fallow              | 7/26/96 | 1:22 PM  | 0           | 0.4                      | 0     |
| Fallow              | 7/26/96 | 1:26 PM  | 0           | 0.4                      | 0     |
| CRP                 | 7/26/96 | 1:45 PM  | 60          | 0.4                      | 20    |
| CRP                 | 7/26/96 | 1:52 PM  | 60          | 0.4                      | 16    |
| Wheatfield irr.     | 8/22/96 | 11:15 AM | 54          | 1.4                      | 30    |
| Wheatfield irr.     | 8/22/96 | 11:25 AM | 57          | 1.4                      | 40    |
| Hayfield non-irr.   | 8/22/96 | 11:35 AM | 14          | 0.3                      | 45    |
| Hayfield non-irr.   | 8/22/96 | 11:41 AM | 16          | 0.3                      | 20    |
| Alfalfa irr.        | 8/22/96 | 11:50 AM | 17          | 12.2                     | 40    |
| Alfalfa irr.        | 8/22/96 | 11:55 AM | 16          | 12.2                     | 65    |
| Range               | 8/22/96 | 12:15 PM | 75          | 0.4                      | 65    |
| Range               | 8/22/96 | 12:25 PM | 80          | 0.4                      | 75    |

Table 36. Cont.

| Plot                | Date    | Time     | Veg.<br>ht. | Soil<br>H <sub>2</sub> O | Cover |
|---------------------|---------|----------|-------------|--------------------------|-------|
|                     |         |          | cm          | %                        | %     |
| Parking Lot         | 8/22/96 | 12:48 PM | 0           | 0.2                      | 0     |
| Parking Lot         | 8/22/96 | 12:55 PM | 0           | 0.2                      | 0     |
| CRP                 | 8/22/96 | 1:12 PM  | 60          | 0.6                      | 35    |
| CRP                 | 8/22/96 | 1:20 PM  | 58          | 0.6                      | 25    |
| Wheatfield non-irr. | 8/22/96 | 1:30 PM  | 23          | 5.0                      | 25    |
| Wheatfield non-irr. | 8/22/96 | 1:35 PM  | 25          | 5.0                      | 20    |
| Fallow              | 8/22/96 | 1:40 PM  | 0           | 0.9                      | 0     |
| Fallow              | 8/22/96 | 1:45 PM  | 0           | 0.9                      | 0     |
| Hayfield non-irr.   | 9/29/96 | 11:30 AM | 10          | 5.1                      | 35    |
| Hayfield non-irr.   | 9/29/96 | 11:45 AM | 14          | 5.1                      | 40    |
| Wheatfield irr.     | 9/29/96 | 11:56 AM | 15          | 2.2                      | 10    |
| Wheatfield irr.     | 9/29/96 | 12:16 PM | 12          | 2.2                      | 15    |
| Alfalfa irr.        | 9/29/96 | 12:27 PM | 30          | 9.3                      | 90    |
| Alfalfa irr.        | 9/29/96 | 12:32 PM | 32          | 9.3                      | 92    |
| Range               | 9/29/96 | 1:00 PM  | 37          | 2.4                      | 25    |
| Range               | 9/29/96 | 1:10 PM  | 49          | 2.4                      | 35    |
| Wheatfield non-irr. | 9/29/96 | 1:36 PM  | 10          | 9.8                      | 5     |
| Wheatfield non-irr. | 9/29/96 | 1:41 PM  | 2           | 9.8                      | 2     |
| Fallow              | 9/29/96 | 1:45 PM  | 0           | 5.1                      | 0     |
| Fallow              | 9/29/96 | 1:50 PM  | 0           | 5.1                      | 0     |
| CRP                 | 9/29/96 | 2:20 PM  | 57          | 2.1                      | 30    |
| CRP                 | 9/29/96 | 2:25 PM  | 60          | 2.1                      | 35    |
| Parking Lot         | 9/29/96 | 2:30 PM  | 0           | 0.1                      | 0     |
| Parking Lot         | 9/29/96 | 2:35 PM  | 0           | 0.1                      | 0     |

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