Modeling Rangeland Health Using Geographic Information Systems and Remote Sensing Methods

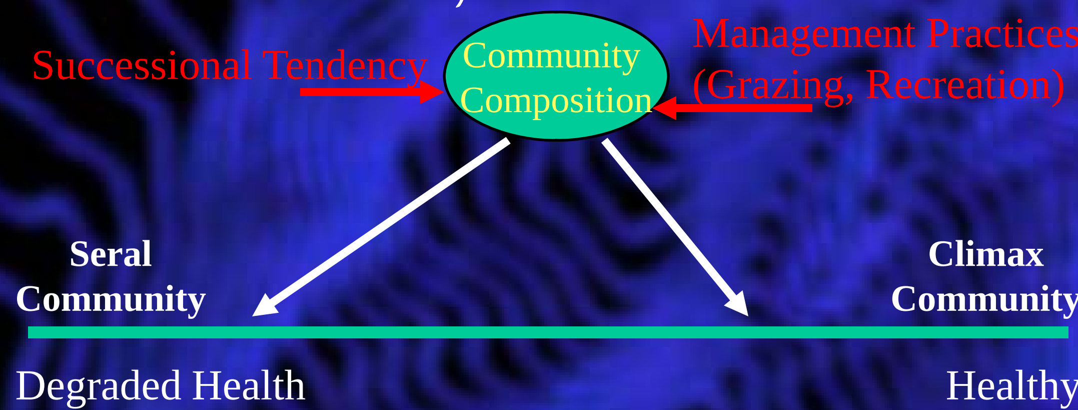
By Jacob T. Tibbitts

GIS Training and Research Center
Pocatello, Idaho

Define Rangeland Health

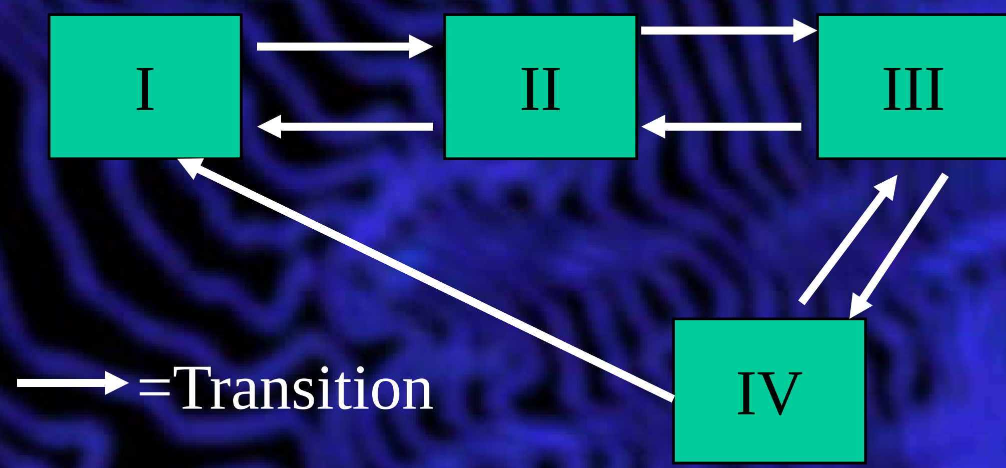
"Rangeland health may be defined as the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained"
(National Research Council 1994)

- National Research Council (1994) advanced this term as an alternative to **range condition.** (Briske et al. 2005).



- Move from Clementsian Model
  - Linear progression toward predictable endpoints (Stringham et al. 2001, Westoby et al. 1989)

- To State-and-Transition Model (Westoby et al. 1989)
  - A catalogue of different plant community compositions and driving variables that may transition a community (state) to another state (Laycock 1991)



Adapted from Westoby et al. 1989

Working Definition of Rangeland Health

- "Healthy rangelands exhibit effective water cycles as indicated by minimal bare earth exposure and minimal evidence of soil erosion. In addition, the vegetation present will be a mixture of grasses forbs, and shrubs that act synergistically to provide quality forage and habitat for wildlife and grazing animals. Litter will be present and biodegrading. Very little, if any, litter will be decomposing through oxidation" (Weber et al. 2004).

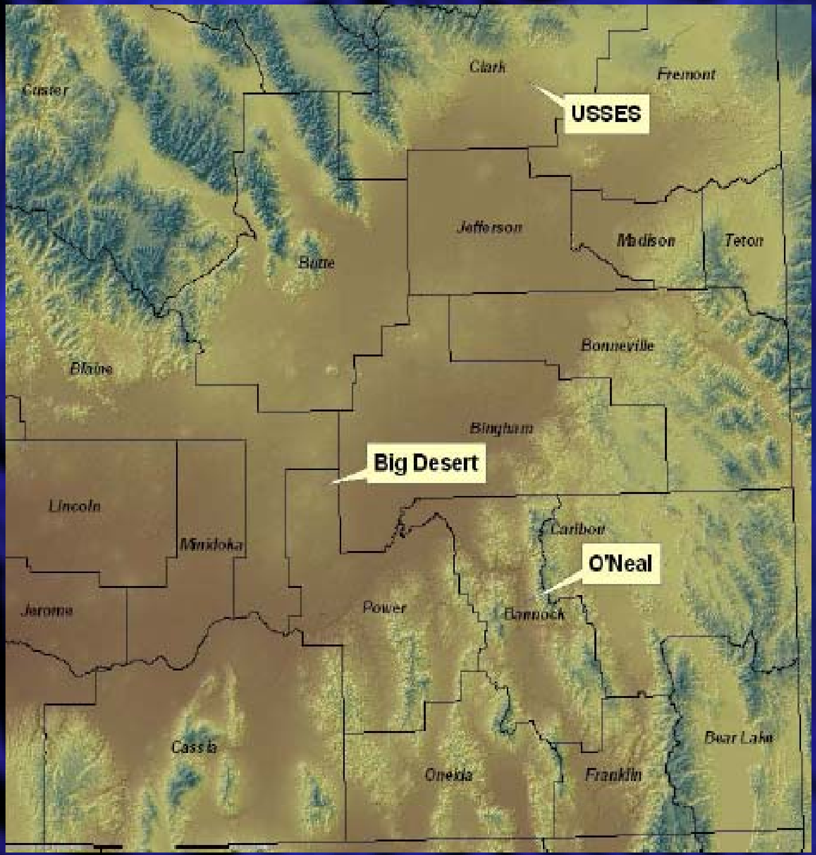
Introduction to This Study

- Use field data and remote sensing methods for the development of a rangeland health model for evaluation and comparison between years or between sites.
  - Examine and establish ecological indicators of rangeland health
  - Determine rangeland health using remote sensing correlated with ground measurements of established indicators
  - Produce a rangeland health model for evaluation and comparison of rangeland sites between years

Objectives of my thesis

Study Areas

- O'Neal Ecological Reserve
  - McCammon, ID
  - Primary research area
- Big Desert
  - NW of Pocatello, ID
- United States Sheep Experiment Station (USSES)
  - Dubois, ID
  - USDA-ARS

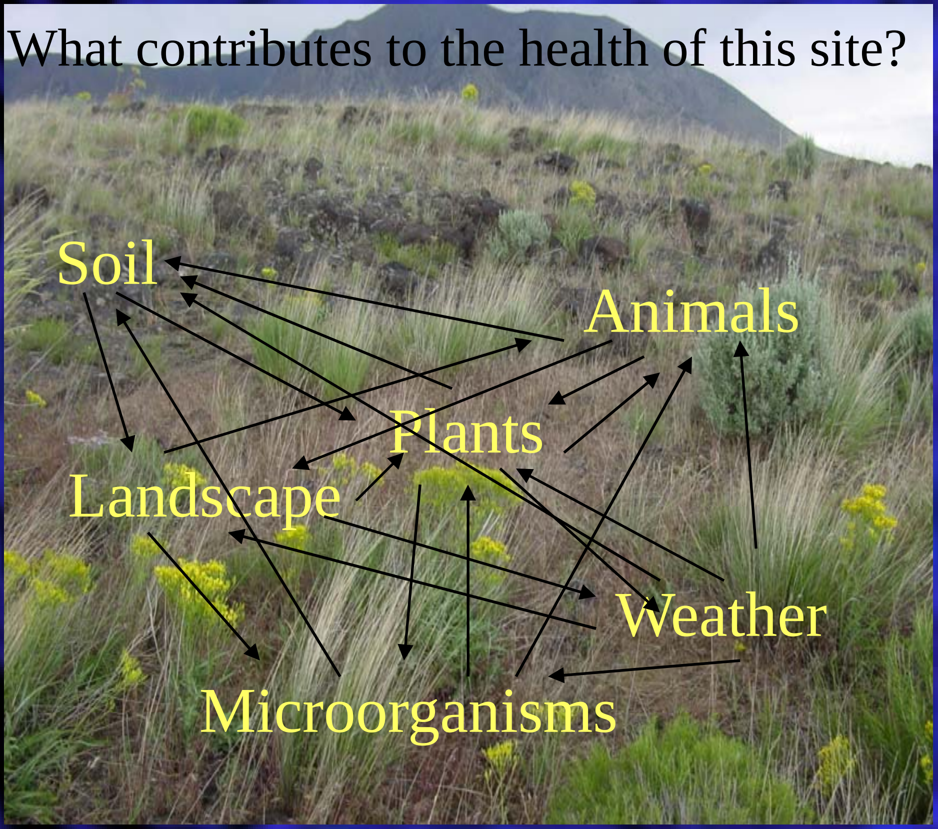


Objective 1: Examine and Establish Ecological Indicators of Rangeland Health

- Evaluate and review currently used indicators
- Determine indicators relevant to this study

Why Use Indicators?

- *"It is difficult and often even impossible to characterize the functioning of a complex system, such as an eco-agrosystem, by means of direct measurements. The size of the system, the complexity of the interactions involved, or the difficulty and cost of the measurements needed are often crippling"* Piorr, H.P. (2003). "Environmental policy, agri-environmental indicators and landscape indicators.". *Agriculture, Ecosystems and Environment* **98**: 17-33.



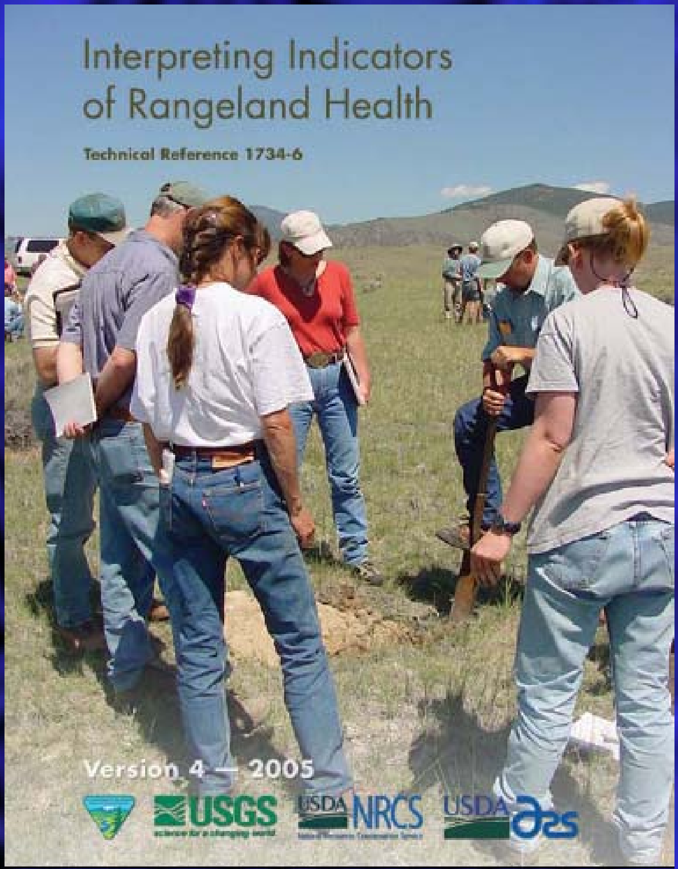
Indicators are used as an index of an attribute that is too difficult, inconvenient, or expensive to measure.

Evaluation of Indicators

- There are practically volumes of studies about indicators used for rangeland and ecosystem management
- Established indicators overlap and become cumbersome and confusing because of the focus on semantics.
- All ecosystem condition indicators are built upon the 3 main ecological processes (with concept of dynamics):
  - Water cycle (capture, storage, and release)
  - Energy flow/cycle (sunlight→plant→animal)
  - Nutrient/Mineral Cycle (biotic and physical)

Review of Indicators

- Interpreting Indicators of Rangeland Health
  - Pellant et al. (2005)
  - Follows recommendations of Pyke et al. (2002) and National Academy of Science (National Research Council 1994).
  - 17 indicators
  - This protocol is used by all major public land management agencies and many private land managers
    - BLM, USGS, USDA-NRCS, USDA-ARS



Review of Indicators- Cont. 17 Indicators of Rangeland Health

(Pellant et al. 2005)

1. Rills
2. Water flow patterns
3. Pedestals and/or terracettes
4. Bare ground
5. Gullies
6. Wind scoured, blowout, and/or depositional areas
7. Litter movement
8. Soil surface loss or degradation
9. Plant community composition and distribution relative to infiltration and runoff
10. Compaction layer
11. Functional/structural groups
12. Plant mortality/decadence
13. Litter amount
14. Annual production
15. Invasive plants
16. Reproductive capability of perennial plants
17. Optional Indicators (biological crusts, vertical vegetation structure)

Review of Indicators- Cont. EPA Indicators Used

- Also adapted from National Research Council, 1994 (Williams and Kepner, 2002)
- Indicators:
  - A-horizon present
  - Rills and gullies
  - Pedestaling
  - Scour or sheet erosion
  - Sedimentation of dunes
  - Distribution of plants
  - Litter distribution
  - Rooting Depth
  - Photosynthetic period
  - Plant age-class distribution
  - Plant vigor
  - Germination and presence of microsites

EPA United States Environmental Protection Agency

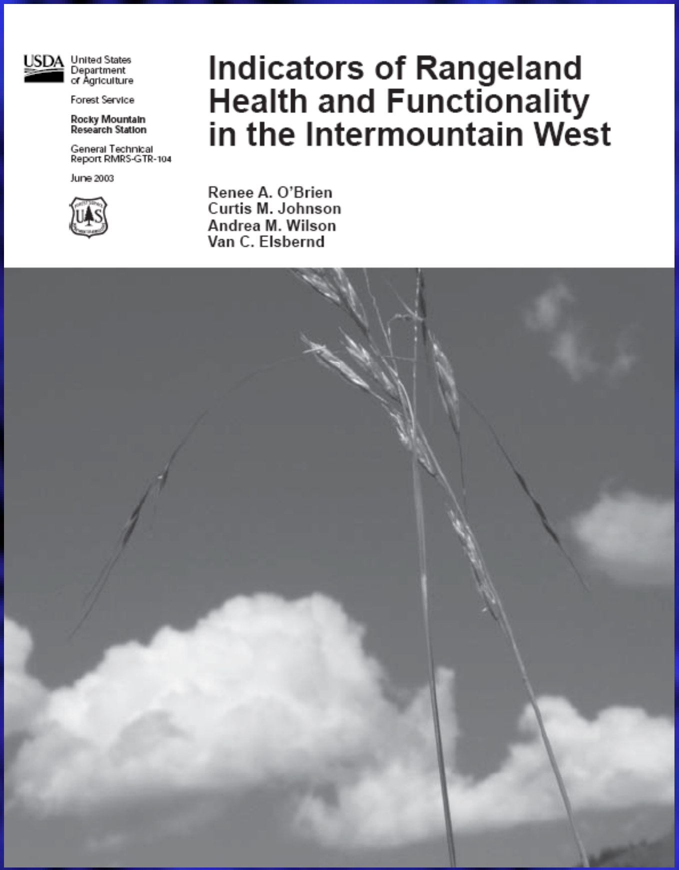
Imaging Spectroscopy for Determining Rangeland Stressors to Western Watersheds

Pollution Prevention and New Technology

Review of Indicators- Cont. Indicators of Rangeland Health and Functionality in the Intermountain West

(O'Brien et al. 2003)

- USDA-ARS study that notes that 11 of 17 indicators from Pellant et al. (2000) deal with some aspect of ground cover protection (inverse of bare ground exposure)
- They conclude that all 17 indicators can be incorporated into just 4
  1. Noxious weeds
  2. Ground cover
  3. Species composition
  4. Shrub cover



Review of Indicators- Cont. Plant Biodiversity and Spatial Heterogeneity/Resiliency

- Landsberg and Crowley (2003) and Whitehead et al. (2001) argue that plant biodiversity and resiliency is the key to healthy rangeland
- Indicators of rangeland plant biodiversity/resiliency used:
  - Extent of clearing
  - Cover of native perennial ground-layer vegetation
  - Distribution and abundance of exotic plant species
  - Distribution and abundance of fire-sensitive species
  - Distribution and abundance of grazing sensitive species
  - Distribution and abundance of listed threatened entities
- Alados et al. (2005) explore spatial heterogeneity to detect change in ecosystem properties (indicators)

Potential Indicators Used In This Study

- This study will be built on the foundational model by Gokhale and Weber (2005) and patterned after O'Brien et al. (2003)
- After reviewing and assessing previous indicators used in other studies and literature, it is realized that these can be incorporated into 8 indicators that are readily coupled to GIS and remote sensing platforms in this study's area of concern (AOC).

Potential Indicators Used In This Study- Cont.

- 8 indicators used:
  1. Bare ground cover
  2. Invasive plants cover
  3. Grass cover
  4. Shrub cover
  5. Litter composition and cover
  6. Erodibility
  7. Ecosystem biodiversity
  8. Ecosystem resiliency (heterogeneity)

"Majority of indicators deal with…some aspect of ground cover protection…the other indicators in the literature deal with the vegetation on the site (and)…species composition." (O'Brien et al. 2003)

Indicators Visited: Bare Ground Exposure

- Consider this indicator a "keystone" to this model
- Bare ground contributes nothing to rangeland health
- "One of the most important factors…is the amount of exposed bare soil." The amount of bare soil exposure is "highly correlated" with LAI, biomass, soil erosion, and is "negatively related to the cover of vegetation and residue." (Hunt et al. 2003)
- If bare ground cover were the only indicator assessed and analyzed, it would be an accurate descriptor of the state, condition, and health of the land (Herrick et al. 2006, Whitford et al. 1998, Booth and Tueller 2003)

Indicators Visited: Invasive Plants

- Invasive weeds indicate land degradation (Mouat et al. 1997, Pyke et al. 2002, Mack 1981, Lacey et al. 1990)
- Early germination of seeds by weedy annuals limits perennial species growth (Peters and Bunting 1994).
- Early senescence changes fire regime (widespread fires) and creates conditions better for weedy annuals (Peters and Bunting 1994) and increases soil erosion.

Indicators Visited: Grass Cover

- "Grasses are not what they used to be" (RCA Issue Brief #10 1996)
- Grassland is considered a Desired Plant Community (DPC) because of the ability to "afford a level of site protection" by being able to "protect the site against accelerated erosion" (Smith et al. 1995) and grass is more preferred than shrubs (Whitford et al. 1998)
- Grass also has an important role in productive and efficient energy harvest and flow and also nutrient (mineral) capture and flow (Pyke et al. 2002, Smith et al. 1995)

Indicators Visited: Shrub Cover

- Shrubs are also a structural group that are crucial to rangeland health (biodiversity, energy flow) (Pellant et al. 2005)
- High amounts of shrub cover can indicate degrading rangeland (O'Brien et al. 2003)
- A high cover of shrub as compared to other functional groups (shrub majority) indicates higher "disruptive water movement" e.g. erosion (Whitford et al. 1998)

Indicators Visited: Litter Composition and Cover

- Litter= Dead, decaying organic matter (American Heritage Dictionary 2004)
- Litter is a functional ground cover group important to erosion and water movement protection, soil integrity, nutrient flow, and moisture retention (O'Brien et al. 2003, Pyke et al. 2002, Whitford et al. 1998)
- Litter does not exist in just one type. It is either biodegrading through biological decay or through oxidation (weathering and chemical decay). Only biologically decaying litter in contact with the ground will fully benefit the rangeland site (Nagler et al. 2000)
- Quantifying litter has proven difficult as is differentiation of litter types (Nagler et al. 2000).*

*See Anticipated Hurdles

Indicators Visited: Erodibility

- Loss of soil is an indication of "loss in site potential" (Pyke et al. 2002)
- Surface soil has the highest nutrient content (Pyke et al. 2002, Wood et al. 1997)
- Soil erosion increases organic matter loss and decreases vegetation cover, biodiversity, and site potential (Pyke et al. 2002)
- An reliable and accurate rangeland erosion model needs to be developed
  - Collaboration with Dr. Corey Moffet (USSES-ARS) to incorporate useful, reliable model
  - WEPP/SPUR, RUSLE, RHEM??

Indicators Visited: Ecosystem Diversity

- Ecosystem stress and status assessments are based on species abundance and diversity (Alados et al. 2005)
- Biological diversity is associated with "efficiency of resource use" (Tillman et al. 1996).
- Plant biodiversity is useful in indicating response to "pressures associated with land use" (Landsberg and Crowley 2004)

Indicators Visited: Ecosystem Heterogeneity/Resilience

- Heterogeneity means spatial-temporal variation (Alados et al. 2005)
- Spatial heterogeneity is a tool to “detect change” in ecosystems (Alados et al. 2005)
- This can be used as a tool to monitor resiliency of a rangeland site after a transition to another state.

Objective 2: Determine rangeland health using remote sensing correlated with ground measurements

- Field research
  - GPS assisted data collection of ground cover classes
- Remote Sensing Analysis
  - Supervised classification of imagery
  - Error assessment

Field Research

- Trimble GeoXT and Trimble GeoXH used to log location of random sample points across AOC
- Visual estimation of bare ground, litter, shrub, and grass using the following categories: None, 1-5%, 6-15%, 16-25%, 26-35%, 36-50%, 51-75%, 76-95%, and >95% (Sander and Weber 2005)
- Each sample point will have the following determined:
  - Dominant weed
  - Shrub species
  - Fuel load
  - Sagebrush age estimate
  - GAP vegetation classification
  - Presence of microbial crust
  - Litter type
  - Available forage
  - Four photographs (N,E,S,W)
  - Soil moisture percentage*
  - Infiltration/Hydraulic Conductivity*

*Only at O'Neal Ecological Preserve

Remote Sensing Analysis

- Supervised classification
  - Use field sites as training site
    - Determine break-point cover percentage—When is a site a training site?
    - Evaluate, explore, and use soft and hard classifiers
      - Fuzzy classification (Zadeh 1965)
  - Incorporate vegetation indices
  - Principal Components Analysis (PCA)
  - Signature extraction
  - Maximum likelihood classification
  - Accuracy Assessment
    - Purify or repeat classification until a reliable model is developed (user accuracy of 75% or better)

Objective 3: Produce a Rangeland Health Model

- Each indicator used in study will initially be a stand-alone model (classification step)
  - Use fine resolution imagery of O'Neal
    - SPOT, Quickbird
- Integrate each model into a comprehensive model (multi-criteria)
- Scale-up model using broad-scale imagery
  - Same conditions as above, just scaled-up
  - MODIS
  - Apply to Big Desert and USSES

Anticipated Hurdles

- Basic component models:
  - Bare earth exposure
  - Vegetation composition
    - Shrub, grass, and forb
- All other indicators will be modeled and incorporated as to achieve highest possible overall accuracy (>75%).
- Some model components may prove unreliable through remote sensing alone.
  - May be difficult to achieve high accuracy through remote sensing alone.
  - If low overall accuracy (<75%), the model will be supplemented with GIS observation data.
  - Questionable components/indicators:
    - Litter model
    - Biodiversity model
    - Heterogeneity model

Significance

- "There is an urgent need for resource managers to know the state of the nation's rangelands, knowledge that is hampered by lack of reliable and continuous data especially over large regional or watershed scales. Development of data collection systems and ecological assessment methods are required to evaluate and monitor these resources" (National Research Council 1994)

Significance- cont.

- There are about 1.1 billion acres of rangeland in the United States--400 million acres of private and 700 million acres of public rangeland (Holechek 2001, Huntsinger and Hopkinson 1996)
- Rangeland ecosystems are extremely important for:
  - Contribution to watersheds
  - Valuable natural resource for livestock forage, wildlife habitat, agriculture, and recreational activities
  - Westoby et al. 1989, Briske et al. 2005, Pyke et al. 2002
- The "inability of the traditional method of range condition and trend analysis to account for the entire spectrum of…dynamics that occurred on rangelands" (Briske et al. 2005)
  - This study's model can account for "entire spectrum" of data and dynamics
- Push for Adaptive Management
  - The "…process of implementing policy decisions as scientifically driven management experiments that test predictions and assumptions in management plans, and using the resulting information to improve the plans" (Moir and Block 2001)

Previous Work

- Rangeland health modeling with Quickbird imagery (Gokhale and Weber 2005)
- Remote sensing and change detection in rangelands (Palmer and Fortescue 2003)
- Rangeland monitoring using remote sensing (Booth and Tueller 2003)
- Fractal analysis of plant spatial patterns: a monitoring tool for vegetation transition shifts (Alados et al. 2005)
- Monitoring rangeland biodiversity: Plants as indicators (Landsberg and Crowley 2003)
- An intelligent GIS for rangeland impact assessment (Vayssieres et al. 1993)
- A protocol for retrospective remote sensing-based ecological monitoring of rangelands (Washington-Allen et al. 2006)
- Recent developments in analysis of spatial and temporal data for landscape qualities and monitoring (Wallace et al. 2004)
- Desertification evaluated using as integrated environmental assessment model (Mouat et al. 1997)

Questions and Comments

GIS Training and Research Center

Pocatello, Idaho