RANGELAND RESOURCES MONITORING:
CONCEPTS AND PRACTICAL APPLICATIONS

by

Benny R. Bobowski

A dissertation submitted in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY
in
Range Science

Approved:

UTAH STATE UNIVERSITY
Logan, Utah
2001
How does one person manage and monitor a half million acres of rangelands towards a sustainable future? Through a journey that begins with the understanding of sustainability, I explore the monitoring concept, two of its applications, and summarize with an emphasis on the art and science of management. Sustainability is a concept that confuses many managers because it is so complex. However, if one considers adaptability as the complement to sustainability, and realizes that an adaptable organism is a sustainable organism, then a manager can relate because the emphasis shifts from that of stability for the future to that of uncertainty for today. The need for monitoring becomes self-evident as it is used to observe the
environment and warn people against the presence of variables thought to be harmful.

Interestingly, professionals who monitor rangelands have not adopted statistical power analysis to aid in change detection. Moreover, range professionals do not have many tools to monitor a half million acres in a statistically and biologically meaningful way. I explored the role of power analysis in evaluating range trend data. In addition, I tested a low aerial photography method for monitoring vegetation cover across rangeland landscapes.

The investigations revealed that when monitoring is used as a feedback loop, the information acquired would likely facilitate adaptability and therefore sustainability of resources and people. However, most monitoring programs offer limited information of low statistical power at an inappropriate scale. Therefore, monitoring information should be used with ancillary scientific information to direct decisions, not drive them. We will continue to rely upon both the art and science of management to keep us following a path towards sustainability.

(143 pages)
ACKNOWLEDGMENTS

I feel very fortunate to have had the support of many people throughout my Ph.D. program. There is no doubt in my mind that the strengths in the ideas and information presented in this dissertation are a direct result of these professional relationships and personal friendships. Though I am grateful to many, I would like to especially thank:

- Allen Rasmussen and John Malechek for initiating my involvement with the National Park Service Student Career Experience Program (SCEP);
- John Spence, John Ritenour, and Joe Alston for providing tremendous support throughout my SCEP program;
- Leroy Smalley for all of your humorous perspective and help in the field;
- Tom Haberle (aka Muffin Man) for your hard work on the computer and on the "Hell Flats";
- Greg Crosby for your patience and persistence in completing the remote sensing project;
- Stephanie Hamblin for all of your skill at jumping through the USU administrative hoops;
B.E. Norton for thinking enough of me years ago to ask me to teach your course during your sabbatical - the experience has forever changed my life;

Allen for being a friend and mentor who has allowed me to ride on the coat tails of your endless energy;

Fred Provenza and Dale Blahna for taking the time out of your hectic schedules to visit with me about a great variety of topics;

Susan Durham for all of your valuable time discussing power analyses;

Kathy Voth for "picking up the slack" with Tehabi during the last few months - it's really peachy of you to do that;

Doug Ramsey for always finding the time to visit and help me out despite your extremely busy schedule;

Bonnie Banner for your help in a pinch;

John S., John M., Ben N., Doug R., and Allen R. for all of your time and guidance as committee members.

And most of all, I want to thank my family - Katie, Taylor, and Ashley. I couldn't have made it without all of you! I love you and thanks for everything!

Ben Bobowski
CONTENTS

ABSTRACT ................................................................. iii
ACKNOWLEDGMENTS ................................................... v
LIST OF TABLES ........................................................ viii
LIST OF FIGURES ....................................................... ix

CHAPTER

1. INTRODUCTION ..................................................... 1
2. MONITORING: IT'S JUST A FEEDBACK LOOP ............... 22
3. VIEWPOINT: ARE YOUR MONITORING DATA POWERFUL ENOUGH TO BE STATISTICALLY AND BIOLOGICALLY MEANINGFUL ..................................................... 37
4. IMPROVED TECHNOLOGICAL AND ECONOMIC EFFICIENCY WITH LOW AERIAL PHOTOGRAPHY APPLICATIONS ON ARID RANGELANDS ................. 57
5. SPECIES RICHNESS ESTIMATES: CAN ONE METHOD FIT ALL SITUATIONS ....................... 84
6. CONCLUSION—ADAPTABILITY: MANAGING AND MONITORING FOR TODAY... HOPING FOR TOMORROW ................. 106

CURRICULUM VITAE ..................................................... 128
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Monitoring definitions</td>
<td>34</td>
</tr>
<tr>
<td>2.2 The range of observed monitoring activities</td>
<td>35</td>
</tr>
<tr>
<td>3.1 A summary of management decisions and their possible outcomes</td>
<td>52</td>
</tr>
<tr>
<td>4.1 Identified thresholds of brightness values</td>
<td>75</td>
</tr>
<tr>
<td>4.2 Cover estimates of the 7 images</td>
<td>76</td>
</tr>
<tr>
<td>4.3 Model estimated values compared</td>
<td>77</td>
</tr>
<tr>
<td>4.4 Summary of the time estimated to perform</td>
<td>78</td>
</tr>
<tr>
<td>4.5 Summary statistics from modeled estimates</td>
<td>79</td>
</tr>
<tr>
<td>5.1 Ten circle plots used to estimate species</td>
<td>97</td>
</tr>
<tr>
<td>5.2 Ten rectangle plots used to estimate species</td>
<td>98</td>
</tr>
<tr>
<td>5.3 Ten square plots used to estimate species</td>
<td>99</td>
</tr>
<tr>
<td>5.4 Average species richness estimates are compared</td>
<td>100</td>
</tr>
<tr>
<td>5.5 The precision of the methods tested</td>
<td>101</td>
</tr>
<tr>
<td>5.6 Summary statistics from the estimates of species</td>
<td>102</td>
</tr>
<tr>
<td>5.7 Summary of the time necessary to perform</td>
<td>103</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 This is an image representing life's paths or the Tree of Life</td>
<td>18</td>
</tr>
<tr>
<td>1.2 This is a new image representing life's paths</td>
<td>19</td>
</tr>
<tr>
<td>1.3 This is a model of the merging of 2 paradigms or domains of thought</td>
<td>20</td>
</tr>
<tr>
<td>1.4 If knowledge is power then wisdom is strength</td>
<td>21</td>
</tr>
<tr>
<td>2.1 The monitoring feedback loop archetype begins with the identification of the values</td>
<td>36</td>
</tr>
<tr>
<td>3.1 An increase in the sample size increases the power</td>
<td>53</td>
</tr>
<tr>
<td>3.2 Power increases as detectable effect size increases in magnitude</td>
<td>54</td>
</tr>
<tr>
<td>3.3 The slope of a linear regression can be related to percent change in density</td>
<td>55</td>
</tr>
<tr>
<td>3.4 Power increases as alpha increases</td>
<td>56</td>
</tr>
<tr>
<td>4.1 Running means were plotted for percent cover</td>
<td>80</td>
</tr>
<tr>
<td>4.2 A cubic regression was performed</td>
<td>81</td>
</tr>
<tr>
<td>4.3 Mean cover values were graphed</td>
<td>82</td>
</tr>
<tr>
<td>4.4 Sample size (images number) is plotted</td>
<td>83</td>
</tr>
<tr>
<td>5.1 The layout of a Modified-Whittaker plot includes three plot sizes</td>
<td>104</td>
</tr>
<tr>
<td>5.2 The species richness mean and 95% confidence intervals are presented</td>
<td>105</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

Background

Congress authorized two public agencies to manage Glen Canyon National Recreation Area (NRA): the Bureau of Land Management (BLM) and the National Park Service (NPS). The BLM is responsible for the administration of grazing permits in accordance with agency policies and the NPS is responsible for all other activities including resource protection. Traditionally, the BLM has managed for multiple and sustained use whereas the NPS has preserved and protected natural and cultural resources. This difference in management philosophy leads one to believe that the agencies have different goals; however, this is not the case. Both agencies are mandated to manage for the protection of resources for future generations [see the NPS Organic Act 1916 and the Federal Land Policy and Management Act (FLPMA) 1976].

Implied in the goal of managing resources for future generations is the notion that resources will be sustained through time. This implication is sometimes clearly
defined (e.g., the multiple and sustained use language presented in FLPMA) but more often than not, is implicit in the language of policy. Regardless of the explicitness of the language, BLM and NPS policies direct managers to employ concepts of sustainability in making management decisions. Given this policy direction and my specific interests, as the NPS range ecologist for Glen Canyon NRA I shaped my academic curriculum to provide time to reflect further upon the concept of sustainability.

As I delved into the academic and managerial dialog regarding sustainability, I found myself initially lost in a myriad of definitions and applications loosely connected in theory and substance. It took considerable thought and interaction with colleagues and mentors to bring some sense of cohesion to this topic. The ideas presented below represent some of the highlights of this exploration of the sustainability concept. These thoughts coalesced through discussions and readings addressing sustainability, monitoring, adaptability, learning organizations, the rise and fall of civilizations, ecosystem management, and various sidebars (e.g., eastern and western philosophy, myths and science, feedback loops, phenomenology, ethnomethodology, paradigms, social construction of
reality, and creativity, to name a few). This exploration is not over; however, I am currently resting on a peak in which the vista is clearer than it has ever been before.

The Sustainability Concept

Sustainability is a "concept cluster"—a particularly complex issue that has within it many smaller complexities. For example, sustainability has been connotatively defined to include attributes such as biological diversity, stability, quality of life, and human life, ad infinitum. Each element is a complex topic unto itself.

The complex elements of sustainability limit one's ability to adequately define the term in other ways. For example, to denotatively define a sustainable biosphere one would have to show such an object. Obviously, this is not possible. Similarly, the term is difficult to define operationally because of its element of temporal infinity and stability. We do not live in a vacuum and we lack an ability to sense the future so as to describe the details of life ad infinitum.

It seems to me that the notion of sustainability is not a very useful concept as a policy directive. Aside
from the complexity associated with its definition, sustainability is often interpreted to mean, and indeed implies, certainty and stability. The expectation of a static environment sets people up to fail because organisms and elements of the environment are in constant flux.

Despite these observations, one does not have to look far in our respective subdisciplines to extract examples of intentions to "maintain" or "sustain" resources at a particular level or state. Fisheries biologists (and foresters) have yet to attain maximum-sustain-yield though policy and directives continue to prescribe such goals (Ludwig et al. 1993); plant community ecologists continue to employ theories of vegetation change and decision criteria based upon a linear, stable, progression of community change (Alston et al. 1999); density relationships between populations of ungulates and their food supply often result in a density population crash during stressful periods (Smith 1980). Keeping artificially high numbers of animals in an area to increase revenue for state game agencies has often exacerbated these crashes.

*Things* extant have maintained themselves in a changing environment that will never repeat itself. We can describe
how they got there; however, the rules change over time.
The future environment will not be like the previous ones
and past performances do not guarantee future successes. To
try to keep things the same in the face of a changing
environment is a seemingly impossible task.

Schopenhauer's essay, *On an Apparent Intention in the
Fate of the Individual*, describes the interplay between
certainty and ambiguity in life.

Schopenhauer points out that when you look back
over your lifetime, it can seem to have had a
consistent order and plan, as though composed by
some novelist. Events that when they had occurred
seemed accidental and of little moment turn out to
have been indispensable factors in the composition
of a consistent plot. So who composed that plot?
Schopenhauer suggests that just as your dreams are
composed by an aspect of yourself of which your
consciousness is unaware, so, too, your whole life.
And just as people whom you will have met apparently
by mere chance became leading agents in the
structuring of your life, so will you have served
unknowingly as an agent giving meaning to the lives
of others. The whole thing gears together like one
big symphony, with everything unconsciously
structuring everything else. And Schopenhauer
concludes that it is as though our lives were the
features of the one great dream of a single dreamer
in which all the dream characters dream too, so
everything links to everything else, moved by the
will to life which is the universal will in nature.
(Campbell and Moyers 1988, page 229)

Schopenhauer suggests that while coping with change in
the present, we often have few clues as to what structures
are going to affect our person, yet it seems very clear
when we have had time to reflect on the past. Indeed, we are also agents in our own and others’ destinies. We are involved in a constant exchange with the environment around us; we change our environments and, in turn, they shape us.

Given this understanding, it seems apparent that the sustainability concept, as currently practiced and understood, places too much emphasis on the past and not enough on the present/future issues of dealing with change. The emphasis is usually on maintenance or stability rather than change and dynamism. It seems to me that there must be a better way to approach the issue of society’s value for life.

An Alternative Perspective

In my opinion, the issue regarding the sustainability of any organism is in the ability of that organism creature to adapt to change. Sustainability, therefore, is an artifact of adaptability. Phrased another way, an organism that adapts to environmental change sustains itself; if it has been sustained, then an opportunity exists for it to adapt to future changes.
It seems there are at least two types of adaptation: 1) that which occurs by the organism engaging in a new environment and 2) that which occurs when the environment affects the organism. Challenges faced by an organism can occur suddenly (e.g., a storm or predatory event) or may come more gradually (e.g., a gradual depletion of resources). These ideas relate to Joseph Campbell's explanation of the challenges people face every day. At times we are flung into situations and at other times we expose ourselves into a new environment.

The emphasis of adaptability is in the present and reflects the ongoing struggle for existence in the face of change. An adaptable individual learns from the past, integrates it with the current condition while striving towards a vision of (or propensity to reproduce in) the future. It adapts through learning and a propensity to live, through action and chance—there are no guarantees!

About eight years ago I was working in Oregon. My boss was heavily involved in the Spotted Owl issues of the Pacific Northwest. He had to leave town to attend another lengthy advisory meeting in Portland and asked me to housesit for him. During a house familiarity tour, he
introduced me to a painting. He made some comments that are vague to me now. However, an image of that painting has stuck with me over the years.

I have attempted to recreate the image (Fig. 1.1). The painting had on it a path that forked into two distinct paths. At the fork in the path stood a signpost with a Spotted Owl perched on top. There was a sign pointing in the direction of each path; each read *The Rest of Your Life*. The background (not represented here) was that of differing scenery for each path. Both paths had potholes and other challenges.

At the time, and for many subsequent years of reflection, I related the image within the painting to that of *The Tree of Life*. It seemed to me that the juncture of the fork was indeed a bifurcation point as in the branches of a tree. Time's arrow shot forward; there was no looking back. Each bifurcation point presented options that were, for all intents and purposes, unrelated. For what it was worth, this idea was reinforced through my master's degree, as I became more familiar with dendrograms through studies of genetics and multivariate statistics (ostensibly, the branching pattern is a common pattern in nature).
More recently, it became very clear to me that there is a better way to represent life. Again, I have attempted to recreate an image (Fig. 1.2). It was striking to me at first because it looked like the symbol for infinity, the so-called lazy eight. The two spheres of the picture represent inflections and transformations in life.

An inflection is the detail in a particular systemic structure. A transformation is a change in a systemic structure. They are joined at a bifurcation point. If one looks at either side of the image one perceives events, and all together, a process. During our lifetimes we tend to focus on events; time is important because it is our referent or benchmark during events. An event has a beginning and an end—birth and death—a finite game with rules, winners and losers. Frequently, people do not recognize that they view life only half at a time (namely events). Or, as many scientists have practiced for centuries, we look at fragments of events for linear causal relationships.

As one reflects upon this, one could argue that processes lie within events and events lie with processes. One would be correct given my current view. I find the best way to comprehend the continua of process and event is
to become familiar with theories of self-organizing systems.

Seemingly distinct components of self-organizing systems - described by the term "holon" - operate based on their own welfare, and they interact to create global behavior. A holon is an autonomous entity when viewed from its constituent subsystems - an individual from the perspective of an organ or cell - but from another perspective, it is merely a component of a larger system - an individual as a member of a social group or as a component of a physical landscape. A holon's behavior influences behavior at larger scales, which in turn influences behavior as smaller scales (e.g., gametes create cells that create individuals that create social groups that create individuals that create gametes), but no holon needs global knowledge to function. (Provenza 1999, page 10)

Like many things in life, we often believe time's arrow to be on a linear path. However, if my mental model holds true, then time's arrow feeds back into itself. Life has neither a beginning nor an end; it just is. A caveat of this is that during periods of inflection and transformation, time is an element that appears to have direction. These ideas emerged from my drawing and reflection on this elemental symbol and quite honestly were somewhat disturbing and exciting. These mixed emotions were unveiled, I believe, because the symbol supports Einstein's assertion that "Time is an illusion" and Prigogine's notion of the definitiveness of a direction to time's arrow.
Thus, if I were asked if life were deterministic or indeterministic, I could only answer—Yes!

In very practical terms (which I am sure you are very eager to relate to at this point), as managers we try to steer life in certain directions at recognized bifurcation points—at times these points are sought out, at other times they find us. Resource managers can be trained to recognize inflections, identify a desired future inflection, identify a probabilistic bifurcation point, and attempt to transform the resource. For example, we survey an area and determine forest cover to be beyond an acceptable percentage (we desire low cover), we identify and apply a prescribed silvicultural treatment that will likely give us our desired (inflection) condition of low cover. Our knowledge to perform this act is based upon rules of past events, of finite games. We can never know all the rules and thus we frequently fail to meet objectives despite the best models.

The Creative Process of Adaptation

I have sketched an image of two domains (or paradigms) of knowledge (Fig. 1.3). The creative process is any act, idea or product that changes an existing domain, or that
transforms an existing domain into a new one (Csikszentmihalyi 1996). Based upon my descriptions (above) of transformation and inflection, one could further define the creative process as the partial or complete transformation of one inflection into another. Creativity is a process.

In my mind's eye, I see adaptability to be the ongoing exchange between an individual and its environment such that a creative process unites (transforms) two or more contrasting domains (paradigms, inflections) into a new, more inclusive, domain. Survival will depend upon the union of new knowledge, new domains of thought, new ways of wisdom. It is frequently argued that to be successful one must know one's domain. We have simplified this notion in society with the saying "knowledge is power." If knowledge is power, then I argue wisdom is strength (Fig. 1.4). Strength is being able to connect domains of knowledge together. An organism needs both knowledge and wisdom to adapt.

Discussion

For adaptation to occur, an individual must recognize that there is a change in the local/global environment that
can affect one's survival or ability to seek out/create a favorable environment. But how does one recognize these changes in the environment that can affect the adaptability, thus sustainability, of individuals, groups, and society?

Typically we see the world the way we believe it to work. How we believe the world to work is based upon our experiences of the past. Order and structure emerge when looking at the past and make up the elements of what we believe to be important. Our ability to perceive the past is dependent upon our paradigms, our mental models that affect our senses, our perception.

Alternatively, we can also believe some new observation we see. When we see a new observation, ostensibly independent of our working model of how the world works, then a contrast is established. This contrast is typically in the form of the disparity between the perception of our environment that was established by looking at our past and our perception of the current environment, a new reality. The observation could be a statistical outlier or some other unexplainable phenomenon. Interestingly, it must be seen through and in contrast to an existing paradigm—it occurs at a bifurcation point. Do
you transform the elements of your current paradigm into a new all-inclusive model? Or do you inflect your current paradigm as you live in the perceived new environment? Depending upon the severity of the new information, a lack of change, which integrates the new information, may result in death.

Adaptability will bring us to many bifurcation points that may require us to transform the current paradigm or practice. Adaptability, thus sustainability, will emerge as a combination of integrating past knowledge in the present environment while striving towards some future desired condition. I believe that we arrive at bifurcation points by recognizing changes in our environment through monitoring. The conclusion that monitoring is a key element of an adaptive, thus sustainable, system has led me to the topic of my dissertation—rangeland resources monitoring: concepts and practical applications.

Practical Issues

Before I discuss the idea of monitoring of rangeland resources both conceptually and practically in the following chapters, it is important to recognize that there are policy and logistical issues that have directed this
First, monitoring is mandated in the agency policies of both the NPS and BLM [e.g., Federal Land Policy and Management Act (1976), National Environmental Policy Act (1969), Endangered Species Act (1973), and Omnibus Management Act (1998)] and therefore can not be ignored. This requirement was further reinforced by the NPS in the newly adopted policy of the Glen Canyon NRA grazing management program. These policies currently drive my work-related activities.

In addition to the policy requirements, there are also at least five logistical constraints to be considered in addressing the concepts, development, and implementation of an agency monitoring program—administrative, boundary, personnel, economic, and scientific. The constraints are described in detail below and are implicitly addressed in the four projects of this dissertation:

1) Administrative constraints—As mentioned above, Glen Canyon NRA has two managers, the BLM and NPS. The administrative responsibilities of grazing belong to the BLM. The BLM is divided into five separate field offices, representing two states (Arizona and Utah). Each BLM field office has partial authority of the
grazing administration of the NRA. This has resulted in five unique management/monitoring programs.

2) Boundary constraints—Grazing currently occurs on 29 allotments representing 880,000 acres of upland and riparian plant communities of Glen Canyon NRA. The majority of these allotments have shared responsibilities because allotment boundaries cross agency boundaries. As a result of these agency partnerships, total acreage of the 29 allotments exceeds 3 million acres. Assessments and consequent management changes should reflect the 3+ million acres currently being managed.

3) Personnel constraints—The current land responsibility of each BLM range conservationist assigned to NPS allotments is approximately 500,000 acres. It has been clearly stated by BLM personnel that while they will assist with the monitoring of the NRA, they can not offer any assistance beyond what they are currently required to do. Moreover, the NPS can allocate the time and resources of only one full-time employee to the monitoring of rangeland resources.

4) Economic constraints—The NPS does not have a dedicated source of money to monitor resources on a continual basis.
5) Scientific constraints—The NPS will engage only in field monitoring activities that can provide both statistically and biologically meaningful information.

References


Provenza, F. 1999. Foraging as science and metaphor: ruminations on life and the habit of change (Draft). Utah State University, Logan, UT.

Fig. 1.1. This is an image representing life’s paths or the Tree of Life.
Fig. 1.2. This is a new image representing life's paths. It differs from the previous in that it feeds back into itself.
Fig. 1.3. This is a model of the merging of 2 paradigms or domains of thought. Wisdom is represented as the area where the two overlap and integrate.
Wisdom = Strength

Knowledge = Power

Fig. 1.4. If knowledge is power then wisdom is strength.
CHAPTER 2

MONITORING: IT’S JUST A FEEDBACK LOOP!

Introduction

Life is an illusion perceived through experience; reality exists in the moment.

A human's experience of the world is unique to each individual. When we try to monitor the world, the reality of the moment is transformed into information perceptible to the senses of the observer. An individual’s ability to perceive is constantly changing as it experiences the interplay between life’s history and its current environment. Think of your own life experiences to recollect how you have perceived the world differently than your neighbor, even though you both observed the same phenomenon.

For individuals of organizations that need to develop a monitoring program, the phenomenon of human observation presents a formidable challenge. It will affect every aspect of a program from determining the variable to monitor to the interpretation of the data collected. How
then can one explain the success of many monitoring programs?

We believe that successful programs operate as a feedback loop. A feedback loop is a system composed of elements that are causally connected such that one element feeds into another until it eventually feeds back into itself. Describing a monitoring system as a feedback loop has two advantages. First, it allows the individual to recognize the elemental components that affect the success of a monitoring program. Second, once the elements are identified, the causal connections within the loop become self-evident. This fundamental understanding will provide for the improvement and success of any monitoring program or procedure.

Monitoring Definitions

The term monitor has its roots in the Latin word *monere*, which means to advise or warn. To warn or advise an individual (or group) implies that the "monitor" has a keen knowledge of that individual's (or group's) desired/expected condition or norm, and of the current condition, and an ability to assess the significance between the difference of those conditions. Interestingly,
there are no temporal constraints associated with the term, contrary to the way the term has come to be accepted today (see Table 2.1).

When one attempts to find a contemporary definition of monitoring, it is clear that there are many deviations from its origin (Table 2.1). Each definition is often unique to a particular author's perspective or subdiscipline. For example, Lund et al. (1998) suggest that the purpose of monitoring is to measure change and model trend. Similarly, Podani (1992) indicates that monitoring should be useful for the comparison of past and present states and should predict the future. A slightly different perspective, presented by Cairns (1979), suggests the purpose of monitoring is to determine environmental quality.

Detailed or situational definitions can provide insights into a process. However, they often lack sufficient structure to provide for general applicability. To address this issue, some authors have attempted to provide an operational definition of monitoring. Hellawell (1991) suggests that the purpose of monitoring is to evaluate compliance with a predetermined standard or an expected norm. Elzinga et al. (1998) provides a similar
definition, though it is specific to management objectives (Table 2.1). These definitions are an improvement upon the previously described contemporaries because they can be readily applied to various situations and they are more consistent with the term's origin. However, despite these more recent attempts to define monitoring, it seems as though the concept could be improved upon.

Monitoring as a Feedback Loop

The concepts relating to feedback loops have been explored in detail for many decades. A feedback loop is considered to be a system composed of elements that are causally connected such that one element feeds into another until it eventually feeds back into itself. A common example of a feedback loop is steering a boat. A course of direction is determined and the helmsman steers in that direction. The helmsman will frequently assess if the boat is deviating from the course. If so, the boat will be steered counter to the direction of deviation. The boat will change direction and the helmsman will assess the situation again. In this example, there is a constant
feedback loop that provides for the maintenance of the boat's course.

The advantage of evaluating the steering of a boat as a feedback loop is that it allows the individual to recognize the elemental components that affect the success of maintaining the boat on course in regards to its referent (the destination). Namely, you have three structures: 1) assessment, 2) steering, 3) a changing deviation. Thus, if we are off course we can evaluate which element of the system is deteriorating and focus on it to improve the whole system.

If we extend this concept of a feedback loop to monitoring, then the definition would be: to advise or warn an individual or group by participating in a feedback loop process that 1) identifies an individual's or group's values, 2) derives objectives from those values, 3) derives variables from the objectives, 4) chooses methods to measure the variables, 5) observes conditions, 6) compares observations to the stated values, and 7) provides an interpretive statement that warns or advises the individual or group of this relationship (Fig. 2.1).

In this scenario the value expressed by the individual or group is the referent by which all elements of the
feedback loop are compared. The values are expressed in the objectives in the form or expected conditions or norms. Objectives are expressed in the variables, and so on until it feeds back to the individuals. After completion of the seven steps (Fig. 2.1), an action could occur if there is an integration of the monitoring information with the originally identified values. The feedback loop may be repeated if it is deemed a necessary action based upon the values of the individuals.

Leveraging the Monitoring System

Each system has elements or structures that generate details unique for any given situation. If one focuses on the details of a system, without assessing the structures and their interrelationships, then corrective actions may provide for only moderate improvements. For our steering example above, knowing the approximate time one has been off course will indeed assist in calculating the appropriate corrective action. However, this is a detail of the assessment structure and cannot be used alone to completely assess the deviation and correct for it.

The alternative to changing the details of a system is to leverage the system using its structures. The notion of
leveraging a system is discussed thoroughly by Senge (1994). The principle is that a small amount of focused energy on a structure will likely have greater influence on the system than any broad-scale effort. Broad-scale efforts typically deal with details that reflect the symptoms of a problem rather than its cause. Moreover, they can be more costly in the short and long term.

To leverage a monitoring system, it must be recognized that to monitor is to address the human value of being advised or warned. Values can be assessed directly or indirectly. In many instances the monitor will indirectly assess values by relying upon laws, regulations, or policy statements that direct a particular institution. Direct assessments of values can be accomplished through interviews with individuals being served. Regardless of the method of identifying the value, the purpose must be to advise or warn because this purpose distinguishes monitoring from similar activities (Table 2.2) such as surveillance and adaptive management (Walters 1997).

It is the monitor’s responsibility to recognize the appropriate individual or social group whose values need to be addressed and to identify them in the detail. The detail will vary. However, identification of elements of
scale and acceptable risk are useful for leveraging the system. The scale of an issue can be demonstrated both spatially and temporally. The issue may be representative of local, regional, or global interests. It may have been specific to a particular time period or of continued interest through time. For example, monitoring forage quality at a particular range site may be of interest for an individual or local people for many consecutive years. Alternatively, it may have been of local, regional, and national interests to monitor for forage quality on a particular tract of public land during World War II for beef production. Today, however, values have changed and forage quality has been replaced with rangeland health.

Identification of the appropriate scale of the issue in time and space will determine the details of the other steps of the process. One way to leverage a particular structure to improve or design a monitoring program is to match the scales of that structure to the stated values. For our rangeland health example, it would be useful to have local, regional, and national input into the variables that are useful for defining rangeland health. Since health can still be a vague term to many, it would be useful to have representatives from differing interest
groups participate in the process of collecting and interpreting information. Indeed this is what land managers of the intermountain west are doing. There has been local, regional, and national input into a set of rangeland health standards and guidelines that are being applied by federal agencies often with the assistance and guidance of Resource Advisory Councils.

Aside from issue identification and scale, one’s ability to detect a particular change in the environment will depend upon the investment of resources necessary for its detection. The amount of resources dedicated to the detection of change in an environmental variable will relate directly to the perceived risk associated with its detection. The more risk associated with not detecting a change typically results in more resources dedicated towards its detection. Thus, an increase in dedicated resources will increase the probability of successfully detecting a change at the expense of occasionally warning of a change when there is none (Type I error). The trade-off is that low investment of resources will likely not detect a change when indeed there has been one (Type II error).
In a monitoring program, the relative importance of Type I and Type II errors should be stated at the time of the identification of the issue. Again, this is a leveraging feature common to all structures because if it is inconsistent with the value at any given point in the feedback loop, then the loop and thus the program are not as robust as they could be.

Conclusions

There are many contemporary definitions of monitoring. Many of these definitions lack the structure and detail necessary to be applicable to a wide variety of situations. To address this issue, we have defined monitoring within the context of a feedback loop. This definition is robust; it is adaptable to any monitoring situation. The key element to recognize is that to monitor is to address the human value of being advised or warned. This value will have components of time, space, and risk that can be used for leverage at any element of the feedback loop. Consistency of these components throughout the process will enhance any program.

The archetype example given above can be used to develop a monitoring program regardless of the sub-
discipline in which one is working. The elements that lie within a monitoring system define the archetype model and its leverage points. We do not suggest that our example is the only archetype for a monitoring program. Rather, we argue that to address a monitoring program as a feedback loop will provide for the design, maintenance, and improvement of any new or existing monitoring program, in any situation.

References


TABLE 2.1. Monitoring definitions: Examples that demonstrate that the literature contains many definitions for monitoring; each definition is somewhat unique to a particular subdiscipline or author’s perspective.

<table>
<thead>
<tr>
<th>Author</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lund et al. 1998</td>
<td>Monitoring is periodic observation at a given location at two or more points in time. Monitoring, preferably through the use of protocols and standards, is the basis for measuring change and modeling trends.</td>
</tr>
<tr>
<td>Elzinga et al. 1998</td>
<td>Monitoring is the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective.</td>
</tr>
<tr>
<td>Hellawell 1991</td>
<td>Monitoring - Intermittent (regular or irregular) surveillance carried out in order to ascertain the extent of compliance with a predetermined standard or the degree of deviation from an expected norm.</td>
</tr>
<tr>
<td>Podani 1992</td>
<td>Monitoring is a SYSTEM of regular observations, both temporal and spatial, that provides information on the state of the environment. It aims to make comparisons between past and present states. Data collected by monitoring are expected to be useful in predicting future changes that are important for man.</td>
</tr>
<tr>
<td>Cairns 1979</td>
<td>Biological monitoring is the regular, systematic use of organisms to determine environmental quality.</td>
</tr>
</tbody>
</table>
Table 2.2. The range of observed monitoring activities: Recall that the value associated with monitoring is to warn or advise. In theory, only assessments and "monitoring" are activities that address those values. In practice however, managers frequently assign secondary monitoring values and expected norms to survey, surveillance and adaptive management programs. While this activity may be useful to some degree, there is a risk associated with assigning a value or expected norm(s) to a process different from the one it was designed for. Investigators may not be able to extract the information necessary to make an informed decision or may more likely make a misinformed decision. Similarly, assessments are repeated through time and compared to one another to detect a trend. There is a risk associated with this practice because assessments are not designed for multiple time periods.

<table>
<thead>
<tr>
<th>Type</th>
<th>Primary Value</th>
<th>Action Type</th>
<th>Temporal Characteristic</th>
<th>Secondary Monitoring Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Survey</td>
<td>Explore</td>
<td>Exploratory</td>
<td>single limited time period</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>used to advise of a particular condition determined by comparing a single or set of norms determined after the fact</td>
</tr>
<tr>
<td></td>
<td>Surveillance</td>
<td>Explore</td>
<td>Exploratory</td>
<td>multiple time periods</td>
</tr>
<tr>
<td>II</td>
<td>Assessment</td>
<td>Warn/Advise</td>
<td>Confirmatory</td>
<td>single limited time period</td>
</tr>
<tr>
<td></td>
<td>Monitoring</td>
<td>Warn/Advise</td>
<td>Confirmatory</td>
<td>multiple time periods</td>
</tr>
<tr>
<td>III</td>
<td>Adaptive Management</td>
<td>Learn (hypothesis testing)</td>
<td>Confirmatory</td>
<td>single or multiple time periods</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>used to warn/advise of a particular condition determined by comparing a single or set of norms determined after the fact</td>
</tr>
</tbody>
</table>
Fig. 2.1. The monitoring feedback loop archetype begins with the identification of the values of the individual or group of interest. The values are expressed in the objectives in the form of expected conditions or norms. Objectives are expressed in the variables, and so on until it feeds back to the individuals interpretation and integration of information. The feedback loop could begin again or an action could take place to terminate the monitoring of the particular value.
CHAPTER 3

VIEWPOINT: ARE YOUR MONITORING DATA POWERFUL ENOUGH TO BE STATISTICALLY AND BIOLOGICALLY MEANINGFUL

Introduction

The application of statistical power to vegetation trend analysis was presented to the range profession over a decade ago (see Tanke and Bonham 1985). Since the late 1970s power concepts have been detailed in books (e.g., Cohen 1988) and journal articles (e.g., Peterman 1990, Green 1989), and more recently in a federal technical report (Elzinga et al. 1998) and a web site (U.S.G.S. 1999). Software packages and programs (see Thomas and Krebs 1997) are available to calculate power. The importance of considering power has been recognized by subdisciplines of resources management (e.g., fisheries, forestry) and among scientific disciplines (e.g., toxicology, psychology). But to date, rangeland managers and scientists have not broadly incorporated this concept. The purpose of this chapter is to review the power concept and to suggest that more than empirical monitoring data are needed to drive management decisions.
A rangeland manager who evaluates the trend of a vegetation attribute (e.g., density, biomass, frequency, or cover) is assessing a null hypothesis. The null hypothesis is that the vegetation attribute is static, or has not changed over time: it is compared to the alternative hypotheses that trend is either up or down. Management actions often are driven by these trend analysis determinations and are potentially misleading when not all of the errors associated with the determination have been scrutinized.

From the statistical testing viewpoint, the manager’s final conclusion is subject to two possible errors known as Type I and Type II. These errors reflect a discrepancy between the determination and the “true,” but unknown, state of nature (Table 3.1). If a manager concludes that a range trend is up (or down) and the decision is consistent with the true state of nature, then the manager’s determination is correct. However, if the true state of nature is static, then the determination is wrong and the manager has committed a Type I error. Similarly, a determination of static trend will be either consistent with the true state
of nature or in error. If the manager determines that the range is static when in fact it has changed, then a Type II error has occurred.

The probability of a Type I error is alpha, the significance level of a statistical test; as such, this error probability is commonly addressed by investigators. The risk of making a Type I error is minimized in statistical tests by setting alpha at a small value, traditionally 0.05. The probability of a Type II error, beta, rarely is calculated by scientists or managers. Power is the complement of beta, computed as (1-beta), and is the probability of correctly determining a nonstatic trend. Power is controlled indirectly by the investigator (Fairweather 1991) as a function of alpha, effect size, sample size, and variance (Peterman 1990). As power decreases so does the probability of detecting change.

There are four options to increase power and thus increase the ability to detect change. First, power increases with increasing numbers of samples. Increasing sample size improves estimates of statistical parameters though costs often increase in terms of time and labor. Second, power increases with decreasing variability among experimental sampling units. The variability among sampling
units can be decreased by increasing the number of samples. It is also possible to consider reducing the variability in the environment by changing the methodology (e.g., quadrat size or shape, sampling design), attribute or the timing of sampling. For example, in many rangeland systems temporal changes in precipitation amounts can alter vegetational cover dramatically through time. If one can measure density or basal cover rather than foliar cover, the variability in the data will likely be reduced because of the removal of the environmental effect, which also illustrates the point that more than one factor can be addressed to reduce sampling unit variability.

Third, power increases with increasing alpha. Historically, scientists and academics have practiced and taught that alpha levels need to be small, traditionally 0.05. However, setting alpha equal to or less than 0.05 is an artifact of our historical computing ability. At one time probability tables were calculated by hand and an alpha of 0.05 became a standard as an artifact of this process. Therefore, while it may be argued that small alphas are used so investigators are highly confident that an effect exists when it is detected, they are considered to be arbitrary.
Fourth, power increases with increasing effect size. This is probably the most difficult to implement because 1) statistical significance is not the same as biological significance, and 2) we often are unaware of what is biologically significant. A biologically significant decline will vary temporally and spatially among species and populations (Reed and Blaustein 1997) and it can be difficult to determine the level of change necessary to result in the extirpation of a species (Pechmann and Wilbur 1994). Invariably, the specification of a biologically significant effect size will be arbitrary (Reed 1996) in the sense that it will be an amalgamation of scientific opinion, values, and politics. Regardless of how one determines the effect size, if the detectable effect size of the monitoring program exceeds that of the biologically significant effect size, then the program should be considered insensitive (Rotenberry and Wiens 1985) and inconclusive (Fairweather 1991).

A standard by which to reference power does not exist, though it has been recommended that power should be equal to 1-alpha (i.e., beta = alpha) (Peterman 1990) or be equal to or greater than 0.8 (Cohen 1977). A better way to determine the appropriate power level is to consider that each error
type has a cost associated with it and that these costs depend upon the question being addressed. The value that managers, scientists, and society place on Type I and Type II errors will be the best determinate of the appropriate power level. Fairweather (1991) argues that Type II errors can be more costly than Type I errors. Resources spent on a false alarm (Type I error) will be costly, but these costs may be short term because the mistake likely will be discovered. Type II errors also incur costs; however, these costs may have both short- and long-term consequences because an undetected problem is more likely to develop serious negative consequences. Managers and scientists who do not address Type II errors implicitly assume that Type I errors are more costly than Type II (Peterman 1990).

Types of Power Analysis

Power can be assessed either a priori or a posteriori. An a priori or prospective power analysis is performed before a monitoring program begins or is used to adjust an ongoing investigation (Peterman 1990). It requires sample data from a pilot study, ongoing investigation, or a similar monitoring program to 1) determine the sample size needed to reach a desired level of power given effect size, variance,
and alpha; 2) determine the detectable effect size given variance, planned sample size, alpha, and beta; or 3) demonstrate relationships between alpha and beta, given specified effect size, variance, and sample size. Performing an *a priori* power analysis allows the investigator to identify monitoring programs that are sensitive to change or likely to detect change (Fairweather 1991, Rice et al. 1998).

An *a posteriori* or retrospective power analysis is performed after the statistical analysis of a monitoring program fails to reject the null hypothesis. The investigator typically wants to know if the determination reflects either the null hypothesis or a low probability to detect the alternative (Peterman 1990). The analysis often utilizes the observed effect size and variance to calculate the probability of the Type II error and thus power. This analysis, however, simply restates the obvious (Thomas 1997). A failure to reject the null hypothesis necessarily results in low power for the observed effect size.

Retrospective power analysis allows the investigator to identify the likely direction of change in an attribute. A confidence interval can be calculated about the effect size to indicate if it is increasing, decreasing, or stable. If
the interval lies above zero, at zero, or below zero, then the investigator can be confident that the observed attribute is increasing, stable, or decreasing, respectively. However, if the confidence interval includes zero and an increase (or decrease), then the investigator must conclude that there is insufficient evidence to support any determination in trend.

A Rangeland Resource Trend Example

For this example, data were acquired from range trend studies performed by the Bureau of Land Management on the Waterpocket Fold allotment, Henry Mountains Resource Area, Utah. The allotment has 3 key areas located proximate to one another. These key areas share the same ecological characteristics including soils, aspect, elevation, and floral communities. One permanent plot was established in 1968 on each of the key areas. A BLM standardized 5’ by 5’ sampling frame was used to estimate density of perennial grass species. Density data were recorded 5 times during the 30-year period in 1968, 1973, 1979, 1984, and 1998.

Data were pooled and analyzed using a simple linear regression in a randomized block (transect) design. The null hypothesis, that the density of perennial grasses had
not significantly changed during the 30-year period, was contrasted with the alternative hypotheses, that the density in perennial grasses has increased or decreased during this period (a 2-tailed test). This information was programmed in SAS 7.0 (SAS 1998) using a macro for sample size analysis (O’Brien 1998).

Regression analysis of the trend data indicated that only 5% of the variability in the data could be explained by a temporal change ($r^2 = 0.05$). The negative slope reveals that there has been a reduction of 65% in the density of perennial grass species yet the slope and the intercept are nonsignificant with p-values of 0.25 and 0.34, respectively. For all intents and purposes, we can fail to reject the null hypothesis.

The observed variance and effect size were used to calculate the power of the equation. There was less than a 20% chance of detecting a change in the density of grasses (power = 0.17). This falls considerably short of the accepted level of 0.8. Further analysis demonstrates that it would take 25 more years of sampling to achieve the recommended power of 0.8 (Fig. 3.1). This monitoring effort is sensitive to detection of changes in the density of
perennial grasses on the key areas only after 55 years of data collection.

A change in effect size would be worthy of exploring. Recall that power is a function of alpha, sample size, variance, and effect size. The observed slope was -0.6577 (Fig. 3.2), which translates into an approximate 29% reduction in grass density from 1968 to 1998. If the desired detectable effect size was increased, would this monitoring program be more sensitive? The answer is yes. However, to achieve power of approximately 0.8 (0.79, Fig. 3.2) the slope would need to be approximately 2, equivalent to an 80% reduction in the density of grasses (Fig. 3.3).

The data available today are inconclusive. A 95% confidence interval for the slope lies between -1.9 and 0.56. The width of the confidence interval reflects the low power and is yet another way to express the utility of these data. Here, the statistical utility of these data is very low; management decisions should not be strongly based on these data alone (Fig. 3.4). Perhaps density is static; but it is statistically possible that density actually is decreasing or increasing.
Management Implications

As the example above illustrates, ignoring power may mislead managers into a false sense of security; low power creates the illusion that something meaningful has been learned (Peterman 1990). This has substantive implications for rangeland managers who use trend data to drive management decisions, particularly when data suggest that trend is static. Most rangeland monitoring programs use relatively small sample sizes to track vegetation characteristics with relatively high temporal and spatial variability, and thus are prone to low power.

The "historic dogma" (Mapstone 1995) related to Type I error has shaped a profession, and indirectly a society, that largely ignores Type II error and thus power. We often interpret the determination of "failure to reject the null hypothesis" to mean that no change has occurred on the rangeland. This belief will likely affect the long-term condition of the rangeland and its stakeholders because many rangeland resource monitoring programs have insufficient power to detect change.

In addition to placing resources and people at risk, ignoring power likely will affect the credibility of managers. Resource decisions are coming under increasing
public scrutiny, and a failure to address Type II error could be perceived as hiding or ignoring uncertainty in decisions. Alternatively, stakeholders with perceptions and experiences that contradict a manager’s evaluation will continue to challenge management decisions in the courts. It will become more difficult to defend decisions that do not account for Type II errors as the statistical bases of decisions become subject to legal and scientific rigor (Millard 1987, Christie 1990, Fairweather 1991).

Management Recommendations

The knowledge necessary to make a perfect analysis of the impacts of potential courses of management action does not exist. It probably never will. But more knowledge is available than has yet been brought to bear on the problem. To be useful, that knowledge must be organized so it makes sense. To say we don’t know enough is to take refuge behind a half-truth and ignore the fact that decisions will be made regardless of the amount of information available... (Thomas 1979, pages 6-7)

Time, personnel, and money will prohibit many rangeland monitoring programs from achieving adequate statistical power. Monitoring information that lacks adequate power can not be used to drive management. We suggest that monitoring information be used with ancillary information such as photographs, written records, climate data, professional
opinion, etc. to direct management. In addition, the
lessons of power extend beyond the crunching of empirical
data. The issue that managers face is the identification
and presentation of the uncertainties in a determination of
“no change” or “no impact.” Managers need to identify, in
specific terms, the relative risks of making a decision.
All decision criteria including alpha, power and expected
costs of Type I and Type II error should be provided and
justified in a decision. An openness to the management
decision process is the only way to give peers and
stakeholders the information necessary to make their own
interpretations and determinations of range monitoring
programs and provide for the long-term benefits of
rangelands to society.

References

Christie, E. 1990. Science, law and environmental

Cohen, J. 1977. Statistical power analysis for the

Cohen, J. 1988. Statistical power analysis for the


Table 3.1. A summary of management decisions and their possible outcomes based upon the test of a null hypothesis.

<table>
<thead>
<tr>
<th>Manager's Determination</th>
<th>State of Nature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trend is Static (do not reject Ho)</td>
<td>Static</td>
</tr>
<tr>
<td></td>
<td>Correct</td>
</tr>
<tr>
<td>Trend is Up/Down (reject Ho)</td>
<td>Up/Down</td>
</tr>
<tr>
<td></td>
<td>Wrong (Type II error)</td>
</tr>
<tr>
<td></td>
<td>Wrong (Type I error)</td>
</tr>
<tr>
<td></td>
<td>Correct</td>
</tr>
</tbody>
</table>
Fig. 3.1. An increase in the sample size (i.e., additional samples through time) increases the power of the test.
Fig. 3.2. Power increases as detectable effect size increases in magnitude. Note that the increase is symmetrical regardless of the sign of the effect, with a two-tailed test.
Fig. 3.3. The slope of a linear regression can be related to percent change in density of perennial grasses. Large changes in density (large effect sizes) have higher power and thus are more likely to be detected.
Fig. 3.4. Power increases as alpha increases. Traditional alpha levels may be insufficient to detect effects of certain magnitude. Note that in the Waterpocket Fold data set, power is unacceptably low even for large alpha values.
CHAPTER 4

IMPROVED TECHNOLOGICAL AND ECONOMIC EFFICIENCY WITH
LOW AERIAL PHOTOGRAPHY APPLICATIONS ON
ARID RANGELANDS

Introduction

On average, a Bureau of Land Management (BLM) range conservationist is responsible for the monitoring and management of a half million acres of rangelands (Personal communication, Hartzell). The vegetation of these rangelands is temporally and spatially variable, as precipitation amounts are often low and unpredictable. To detect change in these environments of relatively high variability, large sample sizes are often needed to estimate parameters well enough to be statistically and biologically meaningful. Unfortunately, range conservationists often do not have the resources to sample intensively and have relied upon sampling strategies designed for stands of vegetation rather than landscapes.

Recent technological advancements have provided some options to help with this problem. For example, low aerial photography has been tested and used locally on rangelands since the 1970s (e.g., Heintz et al. 1979). Low aerial
photography methods have successfully related actual vegetation cover estimates with estimates from photographs providing opportunities to sample large areas remotely. For example, Knapp et al. (1990) calculated correlation coefficients of 0.97 for total cover, and 0.89 for shrub cover on rangelands of southwestern Arizona. These methods have proved particularly useful for estimating cover of shrubs, trees, and total vegetation but have been less successful estimating herbaceous and succulent vegetation.

Despite this technological advancement, this tool has not been widely adopted by range managers. Decisions continue to be directed largely by data that contribute to the information of a site, but are often too weak to be of inferential value to describe a landscape. We believe that several factors have contributed to the lack of adoption of this tool. First, the established methods are expensive and may be cost prohibitive. The use of helicopters (e.g., Tueller et al. 1988) to attain photographs will likely cause budgets to break as they currently cost greater than 10 times more to operate than fixed-wing aircraft. Even if one could use a fixed wing, the estimates of cover using photographs need to be performed manually by an experienced technician. Second, time is limited for a range
conservationist with a half million-acre responsibility, and the manual analysis of every image is likely to be too time consuming to make it a prospect worth trying. Finally, as we have become a digital society it has become less attractive to adopt a technology that was developed with, and depends upon, film.

To address the continued need for an applicable monitoring method that may have a high likelihood of surviving technology transfer, we explored the notion of testing a variety of remote sensing tools for estimating cover of plant life forms. We considered testing satellite imagery but dismissed that option because the low vegetal cover of many rangelands (typically <25% canopy cover) is not easily detected with sensors of resolution of 20 to 30 meters. Shrubs in low precipitation zones absorb significantly less solar radiation (400-700 nm) than shrubs in higher precipitation zones (Ehleringer 1988) and reflectance from vegetation is often overshadowed by the reflectance from soil. We therefore decided to test the accuracy of a low-aerial digital technology (Neale and Crowther 1994) that utilizes computer analysis to provide cover estimates.
Materials And Methods

Study Sites and Site Preparation

Two study sites were sampled on the Waterpocket Fold Allotment located approximately 20 miles northwest of Bullfrog, Utah (37° 45'T35S 110° 52.5'R9E) and managed by the Bureau of Land Management, Henry Mountains Resource Area, Utah. The allotment has 2 key areas located proximate to one another that share similar ecological characteristics including soils, aspect, and elevation. The vegetation communities of the sites are Blackbrush/Mormon Tea communities (Coleogyne ramosissima/Ephedra spp.). However, they differ with shrubs dominant on site 1 and herbaceous plants dominant on site 2.

Twenty-three images of approximately 200 m by 200 m were used in this study. Seven images at site 1 were used for computer model calibration, and 8 images from each of sites 1 and 2 were used for accuracy assessment. Each image estimate had an associated ground reference point for the collection of ground-truth data. Reference points were demarcated with white targets (plastic bags) approximately 4 square meters in size. Targets were 400 m apart in a south to north direction to facilitate the efficient
collection of imagery from the aircraft. Universal Transverse Mercator (UTM) coordinates were recorded for all targets to facilitate flight efficiency and the relocation of targets for the collection of ground-truth data.

Image Acquisition and Preprocessing

The imagery was acquired using the technology described by Neale and Crowther (1994) and the services of the Remote Sensing Services Laboratory, Department of Biological and Irrigation Engineering, Utah State University. Specifically, a fixed-wing aircraft fitted with three 35-mm digital cameras flew at an elevation approximately 378 m above the study site. Each color image represented the Green (0.55 µm), Red (0.65 µm), and Near-infrared (0.85 µm) portions of the electromagnetic spectrum with a grain of 10 cm (0.1 m pixels) and an extent of 40,000 m-squared. The appropriate camera specifications to produce focused images as defined by Lillesand and Kiefer (1994) and Light (1996) were f=35mm, H=378, V=89.41m/sec, t=1/1000 sec. A reflective panel placed near the study site was used to collect baseline radiometric information for camera calibration and image correction.
Image preprocessing included corrections for vignetting, geometric and radiometric distortions. Atmospheric corrections were not performed with the assumption that low-level flying in small spatial areas provides little opportunity for differences in atmospheric attributes. Correction for vignetting was performed by the laboratory following the models of Neale and Crowther (1994). Images were delivered to us for further preprocessing and analysis and are currently archived at the Glen Canyon National Recreation Area Curation Facility (Accession Number 355).

The image enhancement and analysis software, Erdas Imagine 8.4, was used for further processing and analysis on a PC. The edges of the images were cropped to leave approximately the center 1/3 area of the image (130 m x 130 m plot). This is the area of the image that will be the least distorted and best used for data analysis. Each image was then geometrically corrected in a two-step process. Images of 0.5 m resolution were georeferenced to USGS orthophotoquads; then the 0.1 m images were georeferenced to 0.5 m imagery with RMS errors not exceeding 1.5. Each image was then radiometrically corrected following the model of Crosby (Unpublished data).
that included modifications for site location, sun angle, and band calibration.

Ground-Truth Data Collection

The appropriate sample size for ground-truth data collection was determined with a pilot study on a representative area of site 1. Specifically, foliar cover data of vegetation life forms were recorded using a 2X optical point bar set on a tripod with a bubble level. The cover variables recorded included bare ground, litter, rock, shrub (snakeweed - *Gutierrezia* spp. - recorded separately), grass, forb, and succulent. Point-samples were recorded approximately every 2 m along twelve 100-m transects for a total of 600 points.

Data were managed and summarized by cover type in a spreadsheet program. Running means and respective standard deviations were calculated for each cover type and plotted for scientific visualization as described in Elzinga et al. (1998). Variability stabilized for all cover types after 350 points (Fig. 4.1).

Ground reference points were relocated and image prints were used to determine image plot centers in the field. Image prints were kept in clear plastic holders.
and, at each plot, life form observation data of cover types were recorded on the plastic to facilitate model development for computer classification of the imagery.

The north side of the plot was demarcated with a 100-m measuring tape. Seven parallel, systematically spaced (at 14-meter intervals) transects were sampled along a north/south vector perpendicular to the tape. Each transect had 50 equally spaced points for a total of 350. Data were managed and summarized by cover type in a spreadsheet program.

Image Enhancement and Analysis

Images were enhanced to minimize soil background effects. A Soil Adjusted Vegetation Index (SAVI) (Huete 1988) was used with the standard adjustment factor value (L = 0.5). Seven of the resultant single-layer images were analyzed using a supervised classification and modeled against ground truth data to determine thresholds of brightness values for cover types. The enhanced image was displayed in a color scheme that resembled the original image. Brightness values were not merged. The original and enhanced images were compared with the field data to determine where the transition between bare area and
vegetation occurred among the 15 groups of brightness values.

Once the transition group was identified, the percent cover values for the brightness values leading up to and including the low, median, and high values were calculated. Each single-layer image has an associated range of brightness values of 1-255 and each pixel has a value that lies within that range. Percent cover of any class (e.g., herbaceous) is equal to the total number of pixels with brightness values associated with a class (e.g., 1 through 105) divided by the total number of pixels within the image. The fractional value is multiplied by 100 to present it as a percentage.

The cover values of best fit were used in a double-sample estimation process as described by Bohnam (1989). Ground truth data were considered to be the referents that image model data were compared against. Regression analyses and paired t-tests were used to assess the precision and accuracy of the predicted values. Regression analyses were performed on the paired data points to determine model precision. In addition, a paired 2-tailed t-test procedure (alpha = 0.05) was used to test model accuracy. The resultant model was used to estimate cover
on the 16 remaining enhanced images, 8 from site 1 and
8 from site 2.

Practical Application

The practical application of this procedure was
analyzed in 3 steps. First, we attained a level of
proficiency with each task and then recorded the
approximate time it took one person to complete it.
Second, we used the predicted values for the 16 images to
generate the sample sizes needed to detect a 5%, 10%, 15%,
and 20% change in the cover of herbaceous, woody, and bare
variables, respectively. These estimates were determined
given the requirements of power = 0.8 and an alpha = 0.1.
Third, we plotted and summarized the data from steps 1 and
2 to determine the feasibility of this technique.

Results and Discussion

Model Calibration

The imagery was not useful in the identification of
all life forms. The cover values for each of the forb and
succulent forms averaged less than 1% and were undetectable
remotely. The high reflective property of litter made it
impossible to distinguish it from bare area. The
bunchgrasses were difficult to detect for two reasons.
First, the life form has large inter-spaces between leaves that confounded brightness values. Second, the canopy area seldom exceeded the 20cm that would be necessary for its detection with image resolution of 10cm (Jensen 1996).

To address these issues we first pooled the life forms into two categories for analysis: cover (all vegetation) and bare area (rock, soil, and litter). We later completed further analyses of the data by splitting cover into two classes to include herbaceous (grasses, forbs, and succulents), and woody (shrubs, snakeweed, trees) life forms. Litter continued to be calculated within the estimates of bare area. This composite did not substantially bias or limit one’s ability to interpret the hydrological importance of litter cover as most litter was located under plant canopies and not in the interspaces.

A curvilinear model (Fig. 4.2) was developed that related the cover values for bare area determined in the field with the cover estimates determined by the pixel brightness values of the enhanced image for 7 calibration plots from site 1. Cubic regression analyses indicated that the relationship was significant (F-value 6.57, p<0.1) and not likely due to chance, with an $R^2$ value of 0.87.
We considered using this model for further analysis but decided against it for reasons relating to technology transfer. Each enhanced image cover value was estimated through the careful process of relating field notes on images to digital and enhanced imagery. With practice this process was reduced to 20 minutes per image. Although twenty minutes is a small investment of time compared to that needed for the field measurements of a 1,000-m² plot, this process required a priori knowledge of the specific location of life forms in the plot (i.e., data collected from a field trip). We considered this method to be too labor intensive for the constraints of present-day managers.

To address this issue we developed and tested 2 additional models. The brightness value thresholds (Table 4.1) developed from the above model were summarized statistically and the predicted values using the mean and mode were used to recalibrate the paired-plot data. The precision of the model was tested using cubic regression, and the mode (model 1) and mean (model 2) models were not statistically significant with r² values of 0.52 and 0.46, respectively.
We further tested the accuracy of the models with a paired t-test (Table 4.2) and confidence interval analyses (Fig. 4.3). Paired t-tests indicated that the models were not statistically different from the field data. Furthermore, the variability about the mean as depicted using confidence intervals (Fig. 4.3) leads one to conclude that both models are accurate. Given the modest precision of model 1 and its high degree of accuracy, it was used to predict values for the remaining images.

Accuracy tests were further performed to determine the appropriate model to determine woody and herbaceous cover. This final model was used on all images: pixels with the brightness values 1 through 105 = bare; 105 through 112 = herbaceous; and 113 through 255 = woody.

The final model was applied to the 8 remaining images at site 1 and 8 at site 2. Analysis of paired values for individual sites, as well as pooled, provided for estimates of poor precision ($r^2$ values < 0.51) and high accuracy (Table 4.3). Paired t-tests were nonsignificant at alpha = 0.05, suggesting that the modeled predictions are not significantly different from the field measurements.
There were 2 types of investments of time that were necessary to process an image, an initial investment and a recurring investment. The initial investment of time required the collection of ground-truth data and determining a classification model. The recurring investment of time was required for processing every image and this included radiometric correction, enhancement, and classification. Normally, geometric correction would be included also. Indeed, we did geometrically correct each image for research purposes. However, these images cover small areas geographically. The topography varies little within an image and therefore it is not necessary to geometrically correct each sample image for monitoring purposes. The initial investment of time was 18.81 hours for the first image, 2.81 hours for each of the next 6 for calibration purposes, and 0.32 hours for each image thereafter (Table 4.4).

To further explore the practical aspects of this technique we determined the sample sizes needed to detect changes in cover. Sample sizes were determined using a formula provided in Elzinga et al. (1998) and the herbaceous, woody, and bare cover estimates from the 16
images. Calculations conformed to standards for alpha and power to be 0.1 and 0.8, respectively. In addition, the change detection values of 5%, 10%, 15%, and 20% reflect management needs. The necessary number of samples varied according to variable and change detection sensitivity; however, a sample size of 500 would be sufficient for 2/3 of the detection levels (Table 4.5).

We then plotted the initial and recurring investment of time against sample size (Fig. 4.4). A sample size of 500 was used for this exercise and 2 things are immediately evident when the plot is examined. First, the investment of time per image decreases substantially as sample size increases. Second, the investment per sample is less than 1 hour by sample 56. By image 500 the investment in time decreases to less than 24 min per image. Therefore, within 5 weeks time (200 hours) one person could calibrate and process 500 images. These are important observations because traditional methods of image analysis are done manually and unlikely to reach this level of efficiency.

Conclusions

We have refined an old technique into a modern, workable tool. The technique, as currently designed, is a
highly accurate method of detecting changes in the percentage of cover of bare area, herbaceous and woody vegetation. Data were presented that suggested strongly that this is an affordable technique as it takes only 200 hours to monitor thousands of acres. Moreover, the data collected are statistically robust and biologically meaningful at a scale managers have to evaluate regularly. Finally, the images collected are compatible with other remotely sensed imagery and can therefore be analyzed in a variety of other ways to complement larger-scale studies.

This technique is not without limitations, however. It can be improved in at least 2 ways. First, the technology could be tested for model accuracy and precision at scales of finer and coarser resolution to account for the relatively low vegetation cover. If successful, the new resolution will likely facilitate the ability to identify life forms remotely and thus increase the precision of the image estimates. Second, the image correction, enhancement, and classification processes could be automated. Automation would reduce the time investment by half or more and thus increase its economic efficiency.

The modern range professional needs to have available a variety of tools that can offer data of sufficient
biological and statistical rigor to direct monitoring and management decisions. These tools need to address a variety of scales and, as our profession is currently structured, we need to develop more tools to address landscape issues. These tools must be efficient with both time and money or the modern range professional with the half-million acre responsibility will not likely adopt them. Our refinement of an old technique offers one possibility to resolving this issue.

References


Table 4.1. Identified thresholds of brightness values to estimate bare area for individual calibration images (mean of 101 and a mode of 105).

<table>
<thead>
<tr>
<th>Image</th>
<th>Brightness Value</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>105</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>105</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>105</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>105</td>
</tr>
</tbody>
</table>
Table 4.2. Cover estimates for the 7 images used in the model calibration images. Estimates were not significant for the two-tailed t-tests, at alpha=0.05 (n=7).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate (stdv)</th>
<th>Field Measured (stdv)</th>
<th>t-Test Estimate</th>
<th>t-Table Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbaceous</td>
<td>7.22(4.06)</td>
<td>6.49(3.41)</td>
<td>0.281</td>
<td>2.477</td>
</tr>
<tr>
<td>Woody</td>
<td>11.27(2.4)</td>
<td>10.84(5.13)</td>
<td>0.214</td>
<td>2.477</td>
</tr>
<tr>
<td>Bare</td>
<td>84.01(10.42)</td>
<td>82.53(5.72)</td>
<td>0.29</td>
<td>2.477</td>
</tr>
</tbody>
</table>
Table 4.3. Model estimated values compared to the ground-truth field measurements. Two-tailed t-tests are not significant at the alpha=0.05 level (n=8 for individual sites; n=16 for pooled).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate (stdv)</th>
<th>Field Measured (stdv)</th>
<th>t-Test Estimate</th>
<th>t-Table Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Herbaceous</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 1</td>
<td>8.67(7.88)</td>
<td>6.4(2.86)</td>
<td>0.827</td>
<td>2.365</td>
</tr>
<tr>
<td>Site 2</td>
<td>7.29(5.57)</td>
<td>12.6(6.64)</td>
<td>-1.703</td>
<td>2.365</td>
</tr>
<tr>
<td>Pooled</td>
<td>7.98(6.63)</td>
<td>9.5(5.89)</td>
<td>-0.684</td>
<td>2.131</td>
</tr>
<tr>
<td><strong>Woody</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 1</td>
<td>14.6(11.9)</td>
<td>14.1(4.67)</td>
<td>0.13</td>
<td>2.365</td>
</tr>
<tr>
<td>Site 2</td>
<td>12.5(8.27)</td>
<td>8.28(2.83)</td>
<td>1.494</td>
<td>2.365</td>
</tr>
<tr>
<td>Pooled</td>
<td>13.5(9.95)</td>
<td>11.2(4.78)</td>
<td>0.966</td>
<td>2.131</td>
</tr>
<tr>
<td><strong>Bare</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 1</td>
<td>76.72(19.67)</td>
<td>79.5(3.43)</td>
<td>-0.421</td>
<td>2.365</td>
</tr>
<tr>
<td>Site 2</td>
<td>80.24(13.73)</td>
<td>79.11(7.24)</td>
<td>0.218</td>
<td>2.365</td>
</tr>
<tr>
<td>Pooled</td>
<td>78.48(16.49)</td>
<td>79.30(5.48)</td>
<td>-0.202</td>
<td>2.131</td>
</tr>
</tbody>
</table>
Table 4.4. Summary of the time estimated to perform initial and recurring tasks for imagery processing.

<table>
<thead>
<tr>
<th>Time Investment</th>
<th>One Time Calibration Images</th>
<th>All Images</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(hours)</td>
<td>(minutes)</td>
</tr>
<tr>
<td><strong>Initial</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilot study</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Ground truth</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Classification model</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><strong>Recurring</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiometric correction</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Image enhancement</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Classification</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
Table 4.5. Summary statistics from modeled estimates of the cover of bare area used to explore the sample sizes needed to detect change. Predicted sample sizes are calculated with an alpha = 0.1 and power = 0.8. to detect 5%, 10%, 15%, and 20% changes in cover.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Cover</th>
<th>Change from Mean</th>
<th>Actual Change</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbaceous</td>
<td>7.98</td>
<td>5</td>
<td>0.4</td>
<td>2482</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>0.8</td>
<td>621</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>1.2</td>
<td>276</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>1.6</td>
<td>155</td>
</tr>
<tr>
<td>Woody</td>
<td>13.5</td>
<td>5</td>
<td>0.7</td>
<td>1953</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>1.35</td>
<td>488</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>2</td>
<td>217</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>2.7</td>
<td>122</td>
</tr>
<tr>
<td>Bare</td>
<td>78.48</td>
<td>5</td>
<td>3.9</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>7.9</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>11.8</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>15.7</td>
<td>10</td>
</tr>
</tbody>
</table>
Fig. 4.1. Running means were plotted for percent cover by lifeform [1) bare area, 2) litter, 3) grass, 4) shrub, 5) snakeweed, 6) rock]. Succulents and forbs were less than 1% cover and are not represented above.
Fig. 4.2. A cubic regression was performed for the cover values of bare area from the calibration images. Bare area cover (ground-truth data) and (image) estimated values were exponentially transformed with values of 1.6 and -1, respectively. The relationship is significant (p<0.1) with an $R^2$ value = 0.87.
Fig. 4.3. Mean cover values (with associated 95% confidence intervals) were graphed for the bare area attribute of the 7 calibration images using 3 models. The circle • is the ground-truth data; the triangle ▲ is the model using the BV105 threshold; the square ■ is the model using the BV101 threshold; and the diamond ◤ is the original model.
Fig. 4.4. Sample size (images number) is plotted against time (hours) to visualize the dramatic decrease in the investment in time per image as sample size increases.
CHAPTER 5

SPECIES RICHNESS MEASUREMENTS: CAN ONE METHOD FIT ALL SITUATIONS

Introduction

What is the "best" method to measure plant species richness? Stohlgren et al. (1998) compared 4 common sampling plot designs to determine species richness in 4 prairie types of the central grasslands of the United States. Their conclusion was that the Modified-Whittaker (MW) plot method (Stohlgren et al. 1995) was the best sampling method among plot designs in various vegetation communities. However, before one adopts this method for use in these, or other plant communities, several issues should be considered.

The conclusion that the MW method is the best may be misleading because, as the authors noted, the 3 methods tested with the MW were designed to measure other attributes including cover and frequency. The optimum size and shape of a plot is a function of the measurement objectives and the plant distribution patterns within the community. Since the other methods were not designed for
species richness studies nor optimized to reduce the variability among samples (see Bormann 1953), it could be predicted, without field sampling, that the MW plot is more likely to be superior because of the large size of its plots.

In addition to issues regarding the statistical efficiency of the compared methods, there is also a concern regarding the practicality of the MW method for a rangeland manager. On average, a range conservationist in the Bureau of Land Management (BLM) is responsible for the management and monitoring of a half million acres (Personal communication, Hartzell). Range management specialists working for other federal agencies face similar demands. For example, the National Park Service has fewer than 10 range professionals addressing issues on a small percentage of the more than 100 park units that have commercially permitted or historically re-created livestock grazing. The MW method is complex and time consuming relative to other methods and will likely not be readily adopted by agencies (or others) for use. Finally, if species richness estimates are the crux of most popular biodiversity indices (e.g., Shannon Index or SHE Index) and many monitoring
programs, then the attribute estimates must be as accurate and precise as possible to ensure repeatability.

Rangeland vegetation communities are highly variable spatially and temporally because of climatic and edaphic variability. Large sample sizes will likely be needed to detect changes in richness measures and optimum sampling methods will likely vary among plant communities. We tested the accuracy, precision, and efficiency of the MW method with that of plot types optimized for size and shape in Blackbrush/Mormon Tea (Coleogyne ramosissima/Ephedra spp) and Shadscale (Atriplex confertifolia) vegetation communities in northern Arizona and southern Utah.

Materials and Methods

Study Sites

Species richness data were collected at 2 sites located within the 2 common plant communities of Glen Canyon National Recreation Area: Blackbrush/Mormon Tea (Coleogyne ramosissima/Ephedra spp), and Shadscale (Atriplex confertifolia). The Blackbrush/Mormon Tea community (referred to hereafter as Blackbrush community) is located in Arizona (36° 52.5′T41N 111° 37.5′R8E) and has not been grazed for over 30 years. The Shadscale community
is located in Utah (37° 7.5′T42S 111° 22.5′R4E) and continues to be grazed seasonally. The area is considered to be arid with a long-term annual precipitation average of less than 7 inches.

Plot Optimization

Three plot shapes were used in this optimization procedure—a circle, square, and rectangle. Each plot had a limiting dimension of 5 m to maintain observer efficiency with time and effort. This limit defined the threshold beyond which the plots necessarily had to be broken into sections for observation.

The circle had 8 plot sizes (Table 5.1) and the rectangle (Table 5.2) and square (Table 5.3) each had 7. Ten macroplot locations were chosen in representative areas of the Blackbrush and Shadscale communities. One sample for each shape and size was superimposed on another at each of the 10 macroplot sites for a total of 10 samples for each shape/size plot.

We recorded only perennial species for each sample because of the high spatial and temporal variability of annual vegetation in the region (Cully and Cully 1989). The sample data were organized by plot shape and size and
summary statistics were calculated for each shape/size group. The data were then organized for each shape by the plot sample area, beginning with the smallest and ending with the largest (Tables 5.1 to 5.3). The optimum plot was considered to be the last plot size to have a mean increase by one or more species over its previously smaller plot equivalent. After the optimum plot size was determined, it could only be replaced if there was a reduction of 0.25 or more to the standard deviation of a larger plot. These decision criteria were applied to all shapes for both plant communities. The optimum plots for each community were compared to see if they differed.

The optimal plots for sampling the Blackbrush community were to be used in a comparative analysis with the MW method. Sample sizes for the optimal plots were determined by plotting the cumulative number of species for the 10 samples against the number of plots. A trend line was fit to the data to project species richness. The sample size was determined at the location where the trend line crossed 15 species, the estimated number of species in a Blackbrush macroplot area.
Comparing Methods

The MW plot consists of one macroplot and subplots of 3 sizes (Fig. 5.1). We tested this standardized plot at 3 scales: 1) MW(1.0)—its recommended size (Fig. 5.1) (one 50 m x 20 m macroplot; two 5 m x 2 m subplots; one 20 m x 5 m subplot, and ten 2 m x 0.5 m subplots), 2) MW(0.5)—half its size scaled proportionally (one 35.5 m x 14 m macroplot; two 3.6 m x 1.4 m subplots; one 14.1 m x 3.6 m subplot, and ten 1.4 m x 0.35 m subplots), and 3) MW(1.5)—one and a half its size scaled proportionally (one 60 m x 25 m macroplot (1,500m²); two 6.1 m x 2.5 m subplots; one 24.5 m x 6.1 m subplot; and ten 2.5 m x 0.62 m subplots). Each plot was superimposed on the other. The subplots were used to develop collector’s curves (semilog relationships) and predict the number of species in the largest macroplot (1,500m²).

Species richness data for the optimized plots were collected using a stratified random sampling design. The 1,500-m² macroplot was divided lengthwise into 2 plots at its midpoint. The sample sizes for each of the 3 optimal plots (circle, rectangle, and square) were equally divided between the 2 stratified areas. Plots were randomly
located. Data were pooled and a cumulative species richness estimate was calculated for each of the plot types.

The total number of species in the 1,500-m² was assessed and used to test the accuracy and precision of the 6 sampling methods. Paired means were used to perform 2-tailed t-tests (alpha = 0.05) to test accuracy. Data were further analyzed by visually interpreting the plots of sample means and 95% confidence intervals. The precision of the methods was assessed with simple linear regression analyses. The best method would be the one that was the most precise, accurate, and practical.

Practical Application

The practical application of the 6 methods was analyzed in 3 steps. First, we recorded the length of time that it took one person to complete each method. The time included set up, record keeping, and the dismantling of the plots. Second, we used the data collected in the Blackbrush community to estimate the sample size needed to detect a 5%, 10%, 15%, and 20% change in the mean species richness. Sample size estimates were calculated following the formula of Elzinga et al. (1998) with the
specifications of power = 0.8 and alpha = 0.1.

Finally, the time data were used with the sample size data to project and evaluate the amount of time it would take to detect a 10% change in species richness.

Results and Discussion

Optimum Plots

Plot size and shape were optimized for each plant community. The average estimate of species richness using a circle plot ranged from 1.5 to 9 species in the Blackbrush community and 0.4 to 8.2 species in the Shadscale community (Table 5.1). With the use of the aforementioned decision rules, we concluded that the optimum circular plots for the Blackbrush and Shadscale communities were 50 m$^2$ and 28 m$^2$, respectively. The same analysis with the rectangle and square plots similarly revealed that plot sizes were different for each shape between communities. The optimum rectangle plot for Blackbrush was 32 m$^2$ and in Shadscale was 8 m$^2$ (Table 5.2). Similarly, the plot sizes for the square plots were 16 m$^2$ and 9 m$^2$, respectively (Table 5.3). The evidence supports the notion that the optimum plot size and shape is not the same for all plant communities.
Comparison of Optimum Plots with the MW Method

Of the 3 optimal plot types, the circle had the highest average estimate of species richness with the lowest standard deviation. The square plot is less statistically efficient than the rectangle with both a lower mean and higher standard deviation. The sample size needed to accurately estimate species richness of the Blackbrush community for the circle, rectangle, and square plots was determined to be 4, 6, and 6, respectively.

The accuracy of the MW and optimized plot methods were compared to the ground-truth data collected in each of the 1,500-m² macroplots. For five of the six methods evaluated, a 2-tailed t-test (alpha = 0.05; n = 5) failed to reject the null hypothesis that the estimated and actual means were not different (Table 5.4). The notable exception was the square plot that has a significantly different mean estimate of species richness.

Further graphic analysis of each method’s estimated mean species richness and associated confidence intervals supported the notion that the estimates produced by the various methods (excluding the square) were not likely different than the actual ground-truth data from 1,500 m².
(Fig. 5.2). For these five methods, confidence intervals did not include 0, each interval included the mean of the ground-truth data, and the means were not far apart. The mean estimate produced from the square plot is noticeably different from that of the actual richness values. Interestingly, the MW(1.5) is the only method that overestimates richness.

The precision of the methods was analyzed by comparing the predicted species richness estimate to the actual in a paired-plot simple linear regression analysis. Of the 6 methods, only the circle and square had a significant level of precision. The coefficients of variation and associated p-values were 0.85 (p = 0.03) and 0.95 (p = 0.004), respectively. This analysis suggests that while the square is not accurate, it is precise; the circle is both accurate and precise; and the remaining methods are accurate but not precise.

Practical Application

We explored the practicality of using the methods in 2 ways. First, we determined the sample size needed to detect changes in the mean species richness between 2 points in time. Second, we used the sample sizes along
with time efficiency data to determine the time it would take to monitor species richness in the Blackbrush community.

The sample sizes were determined with the criteria set according to accepted standards. Namely, the alpha = 0.1 and power = 0.8. In addition, the detection levels were set to meet managers’ needs for detecting 5%, 10%, 15%, and 20% changes in species richness. The results indicate that all of the MW methods require more replicates then those of the optimized methods (Table 5.6). For example, to be 90% certain of detecting a change of 10% with only a 20% chance of a Type II error, you would need to sample 58 plots for the MW(l.0) and only 11 for the optimal rectangle.

The smaller sample sizes for the optimized methods translate directly into less time in the field (Table 5.7). Each sampling method only takes minutes to perform. However, the optimized plots take less than half the time of the MW plots to complete. From our example above, it is estimated that 29 hours are needed to complete the 58 MW(l.0) plots whereas the 11 circle plots will take approximately 3.6 hours. This is a substantial time difference when you consider the availability of the
professional with a half-million acre responsibility or
the manager with a small operating budget.

Conclusions

In this study, the use of the optimized circle was the
best method. This method was both accurate and precise,
which set it apart from the other methods that could
achieve only one or the other quality. Similar to the
other optimized plot methods, the circle method is
practical and requires a small investment of time to detect
change relative to the MW methods. The biological
advantage of using an optimized plot is that the species
for each sample can be recorded and used in future
interpretations. This is different than the MW method that
depends upon projections of species richness using a
species area curve.

Our observations suggest that one method of species
richness estimation cannot fit all situations without
compromising accuracy, precision, and practicality.
Nevertheless, we support the notion that the MW method can
be a useful method to estimate species richness and detect
changes in monitoring programs. It is evident from this
and other studies that the MW method can provide accurate
estimates for a variety of vegetation communities. However, the caveat is that there are other methods that can be more statistically efficient, biologically meaningful, and practical.

References


Table 5.1. Ten circle plots used to estimate species richness for each of 8 plot sizes. The samples were taken in 2 vegetation communities. The numbers in bold indicate the optimum estimate and thus the appropriate plot size to use in each community. Note that the plot sizes for each vegetation community are different.

<table>
<thead>
<tr>
<th>Radius (m)</th>
<th>Area (m²)</th>
<th>Average Number of Species (stdv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Blackbrush</td>
</tr>
<tr>
<td>0.4</td>
<td>0.5</td>
<td>1.5(0.97)</td>
</tr>
<tr>
<td>0.6</td>
<td>1</td>
<td>2.4(1.08)</td>
</tr>
<tr>
<td>0.8</td>
<td>2</td>
<td>3.7(1.25)</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>4.4(1.43)</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>6.1(1.52)</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>7.4(1.08)</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>8.5(1.35)</td>
</tr>
<tr>
<td>5</td>
<td>79</td>
<td>9(1.94)</td>
</tr>
</tbody>
</table>
Table 5.2. Ten rectangle plots used to estimate species richness for each of 8 plot sizes. The samples were taken in 2 vegetation communities. The numbers in bold indicate the optimum estimate and thus the appropriate plot size to use in each community. Note that the plot sizes for each vegetation community are different.

<table>
<thead>
<tr>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Average Number of Species (stdv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blackbrush</td>
</tr>
<tr>
<td>0.5</td>
<td>0.25</td>
<td>0.125</td>
<td>0.9(0.88)</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>1.8(0.63)</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3.5(1.43)</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>8</td>
<td>5.6(1.27)</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>18</td>
<td>7(1.56)</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>32</td>
<td>8.2(1.48)</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>50</td>
<td>8.5(1.35)</td>
</tr>
</tbody>
</table>
Table 5.3. Ten square plots used to estimate species richness for each of 8 plot sizes. The samples were taken in 2 vegetation communities. The numbers in bold indicate the optimum estimate and thus the appropriate plot size to use in each community. Note that the plot sizes for each vegetation community are different.

<table>
<thead>
<tr>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Average Number of Species (stdv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Blackbrush</td>
</tr>
<tr>
<td>0.25</td>
<td>0.25</td>
<td>0.0625</td>
<td>0.6(0.52)</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.25</td>
<td>1.4(0.52)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2.2(0.92)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4.4(1.35)</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>9</td>
<td>5.4(1.43)</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>16</td>
<td>6.8(1.55)</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>25</td>
<td>7.4(1.51)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shadscale (m²)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0(0)</td>
</tr>
<tr>
<td>0.5</td>
<td>0.4(0.7)</td>
</tr>
<tr>
<td>1</td>
<td>1.8(1.4)</td>
</tr>
<tr>
<td>2</td>
<td>4(1.49)</td>
</tr>
<tr>
<td>3</td>
<td>5.9(1.89)</td>
</tr>
<tr>
<td>4</td>
<td>5.7(1.89)</td>
</tr>
<tr>
<td>5</td>
<td>5.9(1.66)</td>
</tr>
</tbody>
</table>
Table 5.4. Average species richness estimates compared to field measurements (total species richness) for each method. Two-tailed t-tests are not significant at the alpha = 0.05 level (n = 5) for 5 of the 6 methods. The notable exception was the square method which is significantly different from the actual field measurements.

<table>
<thead>
<tr>
<th>Method</th>
<th>Estimate (stdv)</th>
<th>Field Measured (stdv)</th>
<th>t-Test Estimate</th>
<th>t-Table Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified-Whittaker (1.5)</td>
<td>12.6(3.51)</td>
<td>11.6(1.67)</td>
<td>0.745</td>
<td>2.776</td>
</tr>
<tr>
<td>Modified-Whittaker (1.0)</td>
<td>11(4.3)</td>
<td>11.6(1.67)</td>
<td>-0.418</td>
<td>2.776</td>
</tr>
<tr>
<td>Modified-Whittaker (0.5)</td>
<td>10.8(4.09)</td>
<td>11.6(1.67)</td>
<td>-0.523</td>
<td>2.776</td>
</tr>
<tr>
<td>Circle</td>
<td>10.6(2.3)</td>
<td>11.6(1.67)</td>
<td>-2.361</td>
<td>2.776</td>
</tr>
<tr>
<td>Rectangle</td>
<td>10.2(1.79)</td>
<td>11.6(1.67)</td>
<td>-2.064</td>
<td>2.776</td>
</tr>
<tr>
<td>Square</td>
<td>9.8(2.39)</td>
<td>11.6(1.67)</td>
<td>-4.81</td>
<td>2.776</td>
</tr>
</tbody>
</table>
Table 5.5. The precision of the methods tested using a simple linear regression analysis. The coefficient of determination and its associated p-value are presented (ns = not significant).

<table>
<thead>
<tr>
<th>Method</th>
<th>R-Square</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified-Whittiker (1.5)</td>
<td>0.27</td>
<td>ns</td>
</tr>
<tr>
<td>Modified-Whittiker (1.0)</td>
<td>0.58</td>
<td>ns</td>
</tr>
<tr>
<td>Modified-Whittiker (0.5)</td>
<td>0.32</td>
<td>ns</td>
</tr>
<tr>
<td>Circle</td>
<td>0.85</td>
<td>0.03</td>
</tr>
<tr>
<td>Rectangle</td>
<td>0.38</td>
<td>ns</td>
</tr>
<tr>
<td>Square</td>
<td>0.95</td>
<td>0.004</td>
</tr>
</tbody>
</table>
Table 5.6. Summary statistics from the estimates of species richness of each sampling method used to explore the sample sizes needed to detect change. Predicted sample sizes are calculated with an alpha = 0.1 and power = 0.8 to detect 5%, 10%, 15%, and 20% changes in species richness.

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean Species Richness</th>
<th>Change from Mean (%)</th>
<th>Actual Change</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified-Whittaker (1.5)</td>
<td>12.6</td>
<td>5% 0.63</td>
<td>10% 1.26</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% 1.89</td>
<td>15% 2.52</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20% 2.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified-Whittaker (1.0)</td>
<td>11</td>
<td>5% 0.55</td>
<td>10% 1.1</td>
<td>232</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% 1.65</td>
<td>15% 2.2</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15% 2.2</td>
<td>20% 2.2</td>
<td>15</td>
</tr>
<tr>
<td>Modified-Whittaker (0.5)</td>
<td>10.8</td>
<td>5% 0.54</td>
<td>10% 1.08</td>
<td>218</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% 1.62</td>
<td>15% 2.16</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15% 2.16</td>
<td>20% 2.16</td>
<td>24</td>
</tr>
<tr>
<td>Circle</td>
<td>10.6</td>
<td>5% 0.53</td>
<td>10% 1.06</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% 1.06</td>
<td>15% 1.59</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15% 1.59</td>
<td>20% 2.12</td>
<td>8</td>
</tr>
<tr>
<td>Rectangle</td>
<td>10.2</td>
<td>5% 0.51</td>
<td>10% 1.02</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% 1.02</td>
<td>15% 1.53</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15% 1.53</td>
<td>20% 2.04</td>
<td>5</td>
</tr>
<tr>
<td>Square</td>
<td>9.8</td>
<td>5% 0.49</td>
<td>10% 0.98</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% 0.98</td>
<td>15% 1.47</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15% 1.47</td>
<td>20% 1.96</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20% 1.96</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>
Table 5.7. Summary of the time necessary to perform each type of sampling method (note: the Modified-Whittaker method times were estimated for reading the plots). Time data were used in conjunction with the sample size data (Table 6) to project the amount of labor it would take to detect a 10% change in species richness.

<table>
<thead>
<tr>
<th>Method</th>
<th>Time per Plot (min)</th>
<th>N (per Macroplot)</th>
<th>Total Time (min)</th>
<th>Total Time Investment to Detect a 10% Change (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified-Whittaker (1.5)</td>
<td>35</td>
<td>1</td>
<td>35</td>
<td>17.5</td>
</tr>
<tr>
<td>Modified-Whittaker (1.0)</td>
<td>30</td>
<td>1</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>Modified-Whittaker (0.5)</td>
<td>25</td>
<td>1</td>
<td>25</td>
<td>22.5</td>
</tr>
<tr>
<td>Circle</td>
<td>3</td>
<td>4</td>
<td>12</td>
<td>3.6</td>
</tr>
<tr>
<td>Rectangle</td>
<td>2</td>
<td>6</td>
<td>12</td>
<td>2.2</td>
</tr>
<tr>
<td>Square</td>
<td>1.5</td>
<td>6</td>
<td>9</td>
<td>3.45</td>
</tr>
</tbody>
</table>
Fig. 5.1. The layout of a Modified-Whittaker plot includes three plot sizes: 1 = two 5m x 2m subplots; 2 = one 20m x 5m subplot, and 3 = ten 2m x 0.5m subplots. The subplots are within a 50m x 20m plot that is used for calculating the total number of species.
Fig. 5.2. The species richness mean and 95% confidence intervals are presented for each sampling method and the field measurements (total species richness). The sample numbers correspond to the following: 1 = field measurement; 2 = Modified Whittaker(1.5); 3 = Modified Whittaker(1.0); 4 = Modified Whittaker(0.5); 5 = Circle; 6 = Rectangle; and 7 = Square.
CHAPTER 6
CONCLUSION—ADAPTABILITY: MANAGING AND MONITORING FOR TODAY... HOPING FOR TOMORROW

Introduction

On average, a range conservationist is responsible for the management of a half million acres of rangelands. This observation begs the question, how does one person monitor and manage a half million acres of rangelands towards a sustainable future? Better yet, how does anyone monitor and manage towards sustainability? Sustainability is a complex concept to understand let alone apply in principle. And yet, we cannot ignore the issue, as sustainable use of resources is a requirement of many national and international policies.

The reason sustainability is a complex concept to understand is because it contains elements of other very complicated topics such as biodiversity, stability, certainty, and human life ad infinitum. In the day-to-day operations of management, decisions are made with incomplete information and uncertain outcomes. To comprehend sustainability well enough to apply it is a seemingly impossible task.
To address this issue we have tried to rethink what sustainability is in hope that it can be better managed for. If one considers that adaptability is the complement to sustainability, that an adaptable organism is a sustainable organism, then a manager can begin to find ways to manage for it. The emphasis shifts from that of stability of the future to that of the uncertainty of the day.

The necessity for monitoring our environment is very apparent when we consider that we live in an uncertain environment. We want to monitor the environment to warn us of changes so we can adapt, and therefore sustain ourselves. Given this understanding, we explored what monitoring is and how it can be best used towards the goal of sustainability.

Monitoring

The word monitor has its roots in the Latin word monere, which means to advise or warn. Before one can advise or warn anyone, the monitor must have knowledge of the very thing to warn about, observe, and report back to the person or group. In short, to monitor is to participate in a feedback loop.
A feedback loop is a system composed of elements that are causally connected such that one element feeds into another until it eventually feeds back into itself. A common example of a feedback loop is steering a boat. The helmsman chooses a destination and a course is followed. As one motors along one observes (via compass or other observation) that the boat has gone off course. The boat is countersteered to compensate for the course change. Then the process begins again with the observing to see if the boat is on course. The helmsman relies upon continual feedback to keep the boat on course as it oscillates about its current direction (Capra 1996). As the skill of the helmsman improves, then the ability to monitor and respond to course deviations becomes almost automatic (Capra 1996).

The advantage of thinking about monitoring as a feedback loop is further demonstrated by the ability to leverage the system (Senge 1994). That is, once the structures or elements of the system are identified in what Senge refers to as an archetype, then focused energy can be spent on changing how one structure relates to another rather than on the details of the system. For example, if we extend this concept of a feedback loop to monitoring, then the definition would be: to advise or warn an
individual or group by participating in a feedback loop process that 1) identifies an individual's or group's values, 2) derives objectives from those values, 3) derives variables from the objectives, 4) chooses methods to measure the variables, 5) observes conditions, 6) compares observations to the stated values, and 7) provides an interpretive statement that warns or advises the individual or group of this relationship (Fig. 2.1). This is one archetype; there are likely others that will apply to individual situations.

As one develops or participates in a monitoring program, consider that we have identified 7 structures of this archetype: values, objectives, variables, method, observation, analysis, and interpretation. Each structure can be evaluated to see if it is consistent with the others in terms of scale, statistical and economic efficiency, and practicality, and that each reflects the values of those for whom the monitoring is done. The manager who recognizes inconsistencies, and changes them, is leveraging the system. Consider the following to help understand each element of a monitoring system.
Values

If the monitoring system was designed to be consistent with the definition of monitoring given above, then the values of an individual or group should drive a monitoring system. While this may seem like a simple statement, many monitoring programs in resource management have a high turnover rate of seasonal and permanent personnel who are often unaware of the purpose and significance of the data that they collect. When you design or participate in a monitoring program, it may be helpful to ask a few questions such as: Whom are we monitoring for? What are the values of that individual or group (i.e., what do they want to be warned about)? If you are monitoring for a larger group, who are the representatives? Are the values of the representatives consistent with those of the group? Is the policy that guides the monitoring program personal or derived from public opinion? Is it derived from international or national policy?...regional or state policy?...county, city, or office policy?

Objectives

If the values of the individual or group drive the monitoring program, then the objective must necessarily be
derived from those values. The objectives can
directly or indirectly be related to the values of the
individual or group. For example, if a group wants to be
warned when the level of E. coli reaches 200 ppm in the
water of Stable Pond, U.S.A., then we can directly take
this statement and make it an objective. However, if a
group wants to be warned when global warming degrades the
environment, then we would indirectly relate specific
variables (e.g., CO₂ levels) to the overall goal of
detecting the impacts of global warming.

The objectives should relate strongly to the stated
values and reflect the funding and time available for the
program. Moreover, the objectives should reflect the
stated spatial and temporal scale of the values. For
example, it may be inappropriate to monitor an entire
watershed for a month if the area of concern is the water
quality of a pond for the next 5 years. The closer the
relationship between the values and objectives, the better
the feedback will be to the individuals or groups who have
concern. Some questions to consider might be: With what
level of confidence do we want to meet the objective? What
are the acceptable levels of error rates for detecting a
problem when there is none (Type I error) or concluding there is no problem when there really is (Type II error)?

Variables

Many times the program objectives will have clearly stated the variables to be measured. If they do not, then this is the time to identify, with great specificity, the variables to be monitored. Each objective can have a variety of variables that could be used successfully for monitoring. However, each variable will vary in quality and require unique investments of time and money for an expected level of detection. The "best" variable will likely be the one that meets the objectives within the economic and scale constraints of the program. However, there are other questions to consider: Can this variable be measured with accuracy?...with precision? Is this variable reliably measured by the general observer or does it require a skilled technician?

Method

Each variable of choice will have a variety of methods that can be used to measure it. The "best" method will likely depend upon a balance between the desired
sensitivity of the method with the resources (time and money) available for the program. Some questions to think about might be: Does the method have the statistical power necessary for detection of the variable or its change? Is the method suitable for the scale of the objective? Is the method statistically efficient? biologically meaningful? practical?

Observation

Each person observes the world in a unique way based upon the interaction between their ability to sense (nature) and their life's experiences (nurture). As nature and nurture interact, a person's observational abilities change. A very simple example of this is the loss of hearing or sight with age. People often "see what they believe." We are all biased by our paradigms of how the world works and are more likely to make an observation consistent with our beliefs than conflicting with them. We have tried to compensate for our "humanity" with machines. However, it is important to remember that machines are developed, calibrated, and read by humans and our ability to be objective is never as pure as we would like to think. A few questions that might be helpful to ask are: Are the
observers familiar with the assumptions, strengths, and weaknesses of the method? Do the observers have a value system different from that which they are monitoring for? Do the observers believe in the method? Do the individual or groups you are monitoring for believe in the method?

Analysis

Similar to the variable structure, each method will have a variety of analyses that can be used to summarize the data. The "best" method will likely depend upon a balance between the desired sensitivity of the method with the resources (time and money) available for the program. Some questions to think about might be: Is the analysis meaningful biologically? Practically? Is the analysis statistically efficient? Is the analysis the best for the data or is it a "traditional" or "favorite" method of the person doing the analysis?

Interpretation

Though there may be an elitism felt among members of certain groups of people who use language to exclude others from understanding, we must remember that it is just a language, a method of communicating, whether it be
"scientific talk" or "cowboy talk." Language is often built around a knowledge base and likewise a knowledge base is further broadened through use of a language. An ability to use the language and gain its associated knowledge can make an individual powerful within a given domain (e.g., profession, discipline, hobby group) (Fig. 1.3). However, when monitoring is viewed as a feedback loop, then it is recognized that many people with various backgrounds are usually involved.

In a typical example, the "scientist" type person monitors a resource and then communicates the findings to a resource manager who then needs to make a decision that affects a resource user. The scientist, manager, and resource user can operate in seeming separate worlds where one's languages and myths do not easily merge with the other. An ability to understand each other will greatly enhance the opportunity to make a decision that meets concerns of the manager (usually economic or political) with that of the needs of a resource user. With the 3 individuals working to understand each other's domain, an issue of possible conflict may be more easily resolved. The scientist can interpret the data and analysis within the context of science, the manager within the context of
management, and the resource user within the context of use. Merging domains of knowledge can lend themselves to a wise decision for all (Fig. 1.3).

Management Implications

An abstract, intellectual understanding... comes easily enough - I know how many zeros to place after the 10 when I mean billions. Getting it into the gut is quite another matter. (Stephen J. Gould 1987, page 3)

The idea of a monitoring program being a feedback loop is intuitive for many people. Some who have discussed the details of the topic with us were not surprised by our definition. Yet, as Gould so eloquently put it, "getting it into the gut is quite another matter." As we have reflected upon our collective experience, and those of others, we are aware of decades of monitoring information that reside in files without summarization, without interpretation, and without influence on decisions. These data have been collected both with and without an understanding of their purpose and often in association with surveys, assessments, or other investigations that go unused as well. This problem is not owned by any one agency; we have observed, to varying degrees, the phenomenon in all agencies that we have worked with.
The knowledge necessary to make a perfect analysis of the impacts of potential courses of...management action...does not exist. It probably never will. But more knowledge is available than has yet been brought to bear on the problem. To be useful, that knowledge must be organized so it makes sense...To say we don’t know enough is to take refuge behind a half-truth and ignore the fact that decisions will be made regardless of the amount of information available... (Thomas 1979, pages 6-7)

We will likely never have the resources to gather all of the information we would like to bring to bear on an issue. We will continue to address issues with data of insufficient statistical power, often sampled with inappropriate methods, at scales weakly related to the topic at hand. And yet, decisions will be made.

As we consider the art and science of resources management, consider that Romesburg (1981) identifies 3 common methods to use in scientific investigations: induction, retroduction, and hypothetico-deduction. Induction is the process of making general statements about an observed pattern in nature. We do not need empirical data to induce and induction is often done in management and considered to be an art. Retroduction is the process of making hypotheses about the observations of nature. These are often “working hypotheses” in management that are used to justify decisions until proven otherwise. Finally, hypothetico-deduction is the process of making predictions
from hypotheses and testing them. Though this is not often performed with physical experiments in management, it can be performed with thought experiments. "If this is true...then you would expect to see this happen" is a thought or phrase used to understand a situation in the field.

Provenza (2000) points out that the traditional methods of science are based upon principles of differentiation. That is, we have developed processes over the centuries to understand the world around us by separating things apart, to understand its parts—reductionism. Systems thinking is the complement to traditional reductionism and has been developed for about the last hundred years to understand how the parts affect wholes—integration (Provenza 2000). Systemic approaches to understanding problems can be explored through the development and application of systemic models called system archetypes (Senge 1994); this is the process we used to define monitoring.

If these are aspects of the science—differentiation and integration—then what is the “art” in management? In our opinion, the art in management is the ability to meet the needs of people through the union of knowledge to
provide wisdom, of power to provide strength, and of parts to provide a whole (Fig. 1.3). It is a creative process of people akin to that of any artist. It is getting it from the mind into the gut.

Management Application

In the first chapter I identified myself as an NPS range ecologist at Glen Canyon NRA. My experience in this position has provided the context for this dissertation research. I have used knowledge from my work experience to guide my research and, at the same time, have integrated research results into my job. Accordingly, I have used the conceptual model of monitoring as a feedback loop (Fig. 2.1) to improve the effectiveness of current management.

When I began work in this position in January 1998, the relationship between the BLM and NPS was weak. This poor relationship was due, I believe, to the fact that the NPS did not have a person on staff to regularly communicate with the 4 BLM field offices of Utah and Arizona. Additional factors contributing to the poor relationship were, ostensibly, the juxtaposed value systems and policies of the BLM and NPS as well as the personalities of those interpreting and acting upon those policies.
In order to strengthen this relationship, I spent a considerable amount of time identifying and interpreting the policies of the BLM and NPS. I have assumed that the policies reflect the value systems of the public the agencies represent and therefore provide a referent for our actions (i.e., as public servants we should make decisions consistent with the spirit, if not the letter, of policy, thus upholding the value systems of the people). Drawing upon the individual agency's foundations in policy, I have demonstrated to members that the agencies have similar policies with similar mandates and constraints. For example, the language of FLPMA is not only similar to the NPS's Organic Act of 1916, but it also has language that is actually environmentally stronger. In the steps of this process I also dispelled other myths that have persisted for greater than 20 years. For example, when I reviewed Utah BLM's policy interpretation and proposed actions for addressing cultural resources, I found that the language and mitigation requirements were more strict and "protectionist" than NPS policy.

The ability to describe and share similarities in policy, and in the fundamental values that both agencies represent, provided the common ground necessary to
implement changes in the field. That being said, it is important to note that the program approach, my personal approach to management, also included other aspects of finding common ground. For example, I often sought to find similarities between the agencies in management situations, accomplishments, goals, and the values of individual personnel. In addition, the NPS shared resources with the BLM, which has been, traditionally, resource poor. The building of "trust" and establishing common ground has been, and will continue to be, a key element of NPS management and monitoring program.

As I identified the values that drive the monitoring systems and began to explore the ongoing monitoring programs, many of the elements of the feedback loop (Fig. 2.1) became self-evident. Specifically, I could see how foundation policies such as FLPMA provided for the monitoring of livestock forage utilization, and how this information would help the NPS to be compliant with the NPS Organic Act. Moreover, I could understand why all BLM field offices have many of the same objectives and measure many of the same variables. What was less clear, however, is why each BLM field office employed different methods for measuring similar variables (e.g., observing at small
spatial and temporal scales relative to the objectives), assigned professionals of varying levels of experience to perform observations, and used different analysis and interpretation procedures. Equally important was a lack of understanding of why monitoring data have accumulated without feeding back into management processes.

To understand these issues and begin to change management practices it has been useful to use the feedback loop model (Fig. 2.1) as a referent to evaluate the current program. For example, in chapter 3 I explored the statistical validity of how the BLM monitors change in forage plant density. The objective is to measure changes in plant density at an allotment scale (i.e., thousands of acres) and at an interval sufficient to modify permits of livestock use that are issued on an annual basis. The BLM currently measures plant density at sites often less than 25 ft\(^2\) and in time intervals of approximately 5 years. Often these data are analyzed and interpreted to conclude that no change has occurred. Based upon the analysis presented in chapter 3, it could be misleading to conclude that plant density did not change. With this example data set we demonstrated that the method of data collection is at a temporal and spatial scale inconsistent with the
objectives. Moreover, the interpretation of the data was likely to be inappropriate given the limited amount of information collected.

Similarly, the feedback loop model relates to the work described in chapters 4 and 5 and other efforts at Glen Canyon NRA. Chapter 4 addressed the temporal and spatial scale problems by evaluating the practical application of remote sensing techniques. Chapter 5 addressed the issue of measuring species richness. Maintenance of species richness is a common value and objective of both agencies; however, we do not have an efficient method to measure richness given policy and logistical constraints. Finally, NPS and BLM have begun to recognize that monitoring information must be channeled through a management process in order to be useful. Consequently, the NPS has initiated the collection and synthesis of much of our information.

The feedback loop model has provided the framework necessary to improve our existing monitoring program. Interestingly, the only monitoring method that both agencies have been performing and integrating with management is the repeat photography of landscapes. The strength of the repeat photography method is that it can address common values and objectives, it is repeatable
among different personnel, the picture(s) communicate
to a wide audience, and they can be readily analyzed and
interpreted by individuals or groups. While the feedback
loop model did not substantially change this monitoring
technique used by both agencies, it did reinforce the
method's utility and broad application.

Based upon the research findings and observations
summarized above, I extend several recommendations to NPS
management regarding the development and implementation of
a rangeland resources monitoring plan for Glen Canyon NRA.
First, the relationship between the BLM and NPS should
continue to be strengthened. The BLM is the authorizing
agency for grazing on NPS lands; therefore, a mutually
respectful relationship will increase the likelihood of NPS
data being integrated into the BLM management process.
Second, the development of the monitoring plan should
follow the conceptual framework outlined in chapter 2. The
plan should reflect the values of the NPS and address the
administrative mechanisms necessary to ensure that data
collected for this plan feeds back into management
decisions.
The plan should be divided into 2 sections to include both management action and biological information. Management actions by the BLM (e.g., season of use determinations, AUM allocations, Environmental Assessments, etc.) should be monitored to facilitate the interpretation of biological information and to provide an early warning of potential conflicts with NPS policies and resources. The biological information necessary for management decisions should be determined through the efforts of an interagency committee familiar with the resources of the area. The research projects described in this dissertation are refinements to, and evaluations of, current monitoring investigations, and I will recommend that the methods be implemented at Glen Canyon NRA. Finally, I will reinforce the observation that the collection of data that is both statistically and biologically meaningful is often expensive and not possible with current administrative and logistical constraints. However, through the use of appropriate technology and the collection of ancillary qualitative information, we can bring the best available knowledge to bear on resource management decisions.
We shall never achieve harmony with land, any more than we shall achieve justice or liberty for people. In these higher aspirations the important thing is not to achieve, but to strive. It is only in mechanical enterprises that we can expect that early or complete fruition of effort which we call "success." (Aldo Leopold 1991, page 224)

Sustainability is a higher aspiration that we strive for. And, as we continue to strive, monitoring will likely serve as a key element of our system. The monitoring of our environment provides a mechanism to identify potential hazards before they become detrimental to individuals or groups of people. As our environment (local, regional, global, and universal) continues to change, we will need to adapt in order to thrive and survive. If we use our monitoring system as a feedback loop, then we might improve our adaptability, thus the sustainability of our resources and society.

Monitoring, even as a feedback loop, will likely not meet the needs of every situation and should therefore direct decisions rather than drive them. However, before making a decision, we should consider that we often have not exhausted the scientific methods available to us. Indeed, additional information can be generated with
scientific rigor to address both the parts and the whole of an issue without intensive sampling and empirical data. Nevertheless, our perception of any situation will be incomplete. And every situation will require both art and science to continue to move us along the path of sustainability.

References


CURRICULUM VITAE

Benny Robert Bobowski

(April 2001)

CAREER OBJECTIVE:

➢ To improve and maintain our natural resources for future generations.

EDUCATION:

➢ BS in Natural Resource Management, Rutgers University (1991)

➢ MS in Range Science, Utah State University (1997)

➢ PhD Candidate in Range Science, Utah State University (1998-present)

EXPERIENCE:

➢ Range Ecologist, National Park Service, Glen Canyon National Recreation Area, Arizona (January 1998- present)

➢ Instructor, Department of Rangeland Resources, Utah State University, Utah (January 1999-May 1999)

➢ Farm Manager, Green Point Farms, Maryland (March 1997-January 1998)

➢ Lecturer, Department of Rangeland Resources, Utah State University, Utah (September 1996-March 1997)

➢ Teaching Assistant, Department of Rangeland Resources, Utah State University, Utah (September 1995-December 1995)

Biological Aide, National Council for Air and Stream Improvement, Oregon (April 1993-July 1993)

Biological Technician, US Forest Service- Forestry and Range Sciences Lab, Oregon (May 1990-August 1990)

Biological Technician, New Jersey Division of Fish & Game, New Jersey (December 1988-June 1989)

UNIVERSITY TEACHING:


Range/Wildlife Relationships, advanced undergraduate/graduate (1997)

Undergraduate Range Management Examination, undergraduate (1996-1997)

Vegetation Analysis for Livestock and Wildlife, advanced undergraduate/graduate (1996)

YOUTH TEACHING:

Mentor, National Park Service Field Science Partnership, Glen Canyon National Recreation Area (September 1999-August 2000)

Instructor of Natural Resources, National Park Service Field Science Partnership, Glen Canyon National Recreation Area (November 1999-April 2000)
Instructor of Natural Resources, Utah Extension, Utah (January 1997-March 1997)

Instructor of Natural Resources, Cache County Natural Resource Week, Utah (September 1996)

Instructor of Natural Resources, Utah State University Natural Resource School, Utah (July 1996)

SERVICE:


HONORS AND AWARDS:

National Park Service On-the-Spot Award (2000)

Rangeland Resources Monitoring Research Assistantship Department of Rangeland Resources, Utah State University (1998-2000)

Student Career Education Program, National Park Service (1998-2001)

E.L. and Inez Waldron Biotechnology Endowment Fund Award (1996)

U.S. Forest Service Research and Education Grant, $19,000 (1994 - 1996)

Service Award, Transcontinental Gas Pipeline (1991)

GRANTS ($126,650):

National Park Service Fee Demonstration Project Grant, $85,800 (FY2000/2001)
National Park Service Fee Demonstration Project Grant, $34,200 (FY2000/2001)

Colorado Plateau Cooperative Ecosystem Studies Unit Fee Demonstration Project Grant, $2,750 (FY2000)

Problem-based Learning Grant, College of Natural Resources, USU, $900 (FY1999)

National Council for Air and Stream Improvement Research Grant, $3000 (FY1995)

PUBLISHED ABSTRACTS & PROFESSIONAL PRESENTATIONS:


Students, Academics, and Citizens. George Wright Society Biennial Conference, Denver, Colorado. (Submitted)


PEER-REVIEWED PUBLICATIONS:


OFFICIAL REPORTS and PLANNING DOCUMENTS:


CONTINUING EDUCATION:

- Annual Meeting for the Society for Range Management. 1999. Omaha, Nebraska. (16 hours)
- Annual Meeting of the Ecological Society of America. 1996. Providence, Rhode Island. (32 hours)
- Preparing to Teach Workshop. 1996. Sponsored by the Ecological Society of America, Providence Rhode Island. (4 hours)


Sharing Common Ground: A Livestock/Big Game Symposium. 1991. Sparks, Nevada. (24 hours)

TRAINING


Cultural Considerations of a Diverse Workforce. 1999. Sponsored by the National Park Service with Jeff Thompson, Consultant. (16 hours)
