# Tactical themes for rangeland research

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**Abstract.** The problems threatening the conservation and management of rangeland, over one-half of the world's terrestrial surfaces, are significant and growing. Current assessments of drivers and externalities shaping these problems have resulted in strategies intended to result in sustainable development of these lands and their resources. However, how can individual scientists and individual research programs support the needed strategies and goals? What can we realistically contribute and accomplish? We believe that technology can connect individual scientists and their science to the problems manifest in rangelands over the world, in a more rapid exchange than has occurred in the past. Recognition of local challenges, innovations, and scientific tests of the effectiveness of our technological solutions to these problems can keep pace with rapid change and help us adapt to that change. However, to do this, we have to invest in a process of connecting science to landscapes. Our tactics are to link, openly and collaboratively, the scientific method to discrete, specific, managed landscapes. We term these collective tactics, our fundamental research theme, "*Landscape Portals*". All of the elements of this theme exist currently, to various degrees, but they lack cohesion and interactive, real-time connections. Future investment requires two basic, tactical scientific behaviors: a post-normal application of science in support of land management by hypothesis and a scientific method modified to accommodate a data intensive scientific inquiry directed towards adaptive management. These behaviors support our "*Landscape Portals*" theme: science conducted in a highly interactive, transparent, data enriched, locally relevant, globally connected, popularly translated, and ecologically robust manner.

**Keywords:** Landscape ecology, rangeland management, geospatial portals, ecography, ecological sites, data-intensive science.

## Introduction

Development of a vision for relevant rangeland science is strongly limited by factors that shape existing perspectives and the perceived constraints upon those perspectives. Any statement about future scientific themes and their possibilities should, in the interests of clarity, offer a review of the existing perspectives and constraints. We envision seven key drivers and externalities that will shape our thinking about the future and drive the research themes that we think are important to our clients, partners, stakeholders, and the broader public. These seven factors are a mixture of cultural, social, environmental and technological forces. However, our clairvoyance will be wasted if we lack the support and resources needed to pursue those research themes that may positively affect the management of our natural resources.

It is not just the themes that are important, but how these themes both engage and capture the imagination of a larger public. Typically, that public is basically urban, largely unconnected to the land, and disinterested in uninspired or dull themes, well founded or not. Our perspectives emerge from this ideology.

Our seven drivers and externalities are not unique perspectives. These perspectives, and others, have led to recent, well-articulated strategies meant to shape policies that will result in the sustainable development of land and its resources (Griggs *et al.* 2013, Reynolds *et al.* 2007, Morton *et al.* 2011). However, as individual scientists, we need to employ tactics that will service these well-informed strategies. The drivers and externalities we present in this paper strongly influence the tactics that we see as important for our overall research theme. First, there are 2 key scientific behaviors that underlie our theme: (1) contextualized science, or science in support of resource management by hypothesis (Sayre *et al*. 2012); and (2), an interactive scientific method shaped by data-intensive inquiry in a manner described as the "fourth paradigm" (Hey *et al.* 2009).

From these behaviors emerges our fundamental theme of "Landscape Portals": science conducted in a highly interactive, transparent, data enriched, locally relevant, globally connected, popularly translated, and ecologically robust manner. This is a theme that is oriented towards science-based principles and tools for local management of grasslands and rangelands, but it is more widely informed by global science and relevant to global citizens. All of the elements of this theme are currently present, to various degrees, but they lack cohesion and interactive connections. Our goal is to create globally available knowledge, information and tools that can be readily utilized at local levels as needed by people in their conservation management decisions and practices.

## Drivers and Externalities

### *Asia and India*

Global dynamics continue to be strongly influenced by trends within Asia, especially China, and India. Figures 1a-d present selected data drawn from FAO (2011) that illustrate the influence of Asia and India in recent decades on population growth and resources devoted to food production. Two primary observations are drawn from these figures: (1) growth in human population and efficiencies in food and animal production in China has strongly influenced global trends over the last 3 decades; and (2) growth in human population and efficiencies in food and animal production in India will increasingly influence global trends in coming decades. Any research theme has to be applicable and capable of application in Asia and India to be effective and relevant.

### *A World with Less Grass*

The majority of the world's native terrestrial surfaces are dominated by woody species, not herbaceous plants (Fig. 2). Landscapes dominated by woody species are four times more common around the globe as those dominated by herbaceous species. Furthermore, there is twice as much area classified as either extreme desert or tundra than is characterized as grassland. . For several reasons, the amount of grassland-dominated area is less than in recent decades and is anticipated to continue to decline in coming decades (Hughes 2003, Van Auken 2009). Of extreme relevance is that many managed landscapes are a mixture of types, either in terms of potential or existing vegetation states, or both. Any research theme needs to be cognizant of the temporally dynamic and spatially heterogeneous nature of these lands (Bestelmeyer and Briske 2012). Of particular importance is the need to reflect these distinct

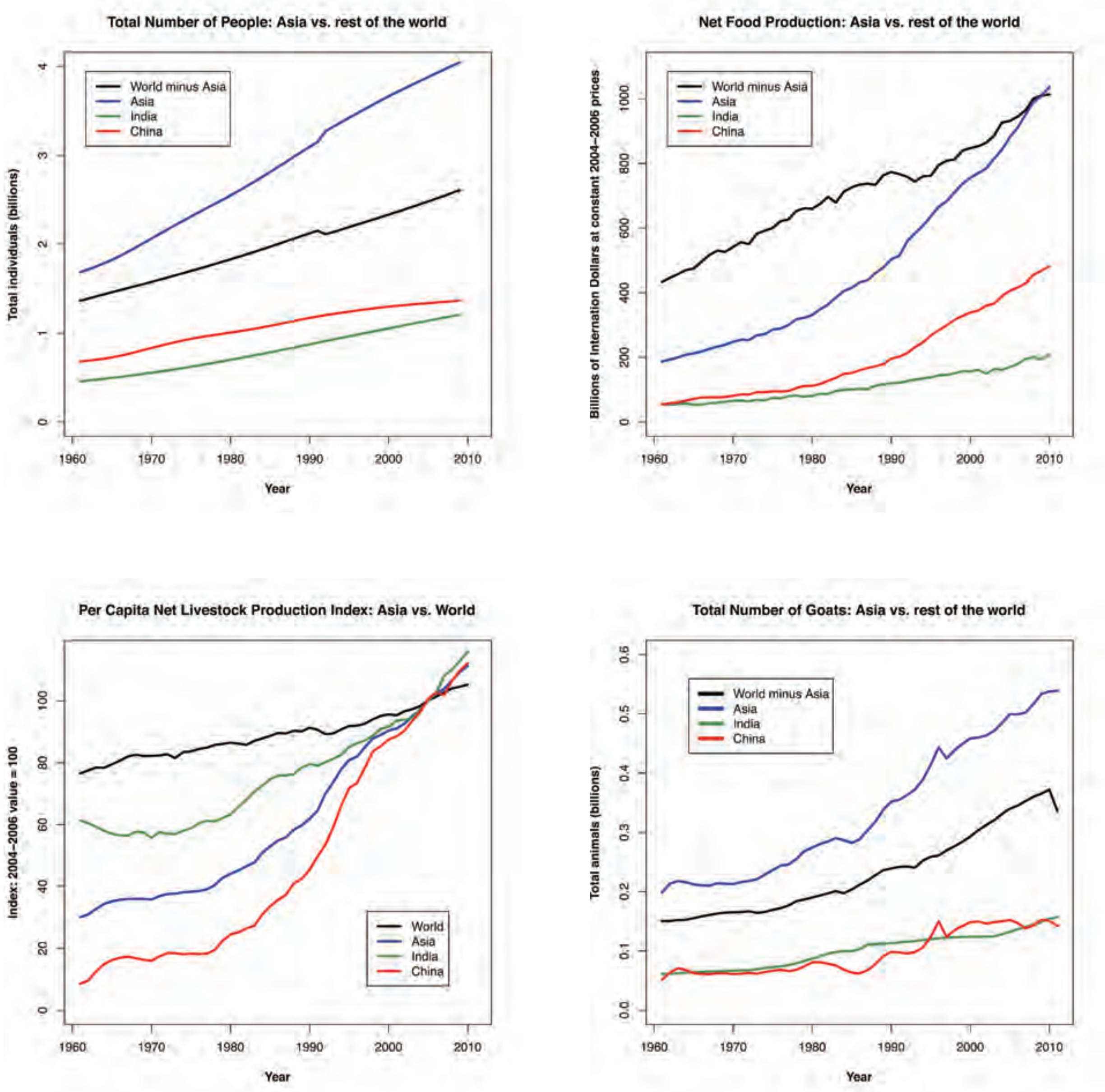


**Figure 1. Contrasting changes in human population and selected agricultural related statistics for India, Asia, and the rest of the globe over the past 5 decades. (A) total number of people; (B) net food production; (C) per capita net livestock production; and (D) total number of goats (data drawn from FAO 2011).**

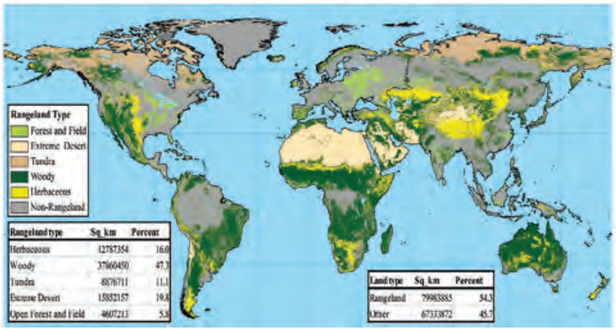


**Figure 2. Global rangeland distribution based on an assimilation of 72 land cover classes into one of five rangeland types or non-rangeland – from Estell *et al.* (2012, as adapted from US Geological Survey 2008).**

heterogeneities, in terms of ecological potential as well as current status, within any specific landscape.

## *Network Technologies*

An ability to employ computers in daily life is now regarded as the 5th utility, along with electricity, gas/energy, water and telephone (Buyya *et al.* 2009). This integration of computing into all aspects of daily lives for nearly 60% of the world's population has had tremendous effects on human cultures, economies, and science (Goodchild *et al.* 2012). These impacts create challenges but also opportunities.

It is estimated that 4 billion people have Internet access on a regular, reliable basis (Craglia *et al.* 2012). A Digital Earth Index (DEI) reflecting a ratio of Internet adoption to dependency on digital equipment and goods has been developed for each country. Countries within Europe, North America, Oceania and Asia typically have a DEI well above 1.0 reflecting a high adoption rate of digital technology relative to energy consumption.

Unfortunately, much of the world, especially rural regions and less developed countries, lack the needed infrastructure to support the digital age. Their Internet adoption rates are relatively low with DEIs well below 1.0. However, creative efforts are underway to provide Internet access to these remaining 3 billion people around the world. Often, access is limited or absent because supporting infrastructure, primarily a reliable electrical grid, is lacking in remote, rural, and/or impoverished areas. Advancing technology is being brought to bear on these limits (Ranaboldo *et al.* 2013). For example, in rural parts of India, micro-electrical grids are possible that exploit renewable energy-based decentralized electricity (Nouni *et al.* 2008). Though these developments face technical constraints, the opportunities to create stand-alone micro grids based on renewable energies are real and being actively pursued. Any research theme needs to be Internet nimble given that in the near future all humans will have Internet access.

## *Long-Term Drought and Mega-Fire*

Long-term droughts (>12 months in duration) over large regions of Asia, Africa, the Mediterranean and the Americas are projected to become 3 times more frequent during the later half of the 21st Century (Sheffield and Wood 2008). Observed aridity in global systems through 2010 support model projections of increased drought occurrence throughout the 21st Century (Dai 2013). Though ranchers and pastoralists are well acquainted with managing landscapes during droughts, the emerging long-term drought scenarios will require increased management and policy flexibilities (Ash *et al.* 2012).

Compounding these projections for increased drought occurrence is evidence that mega-fires in the world's woody ecosystems may be more likely in the future. In fact, mega-fires have been viewed as positive feedbacks to climate change (Adams 2013). It is alarming that, at any point in time, there is widespread occurrence of fire around the globe on all continents (see NASA 2013). The nature of mega-fires goes beyond their simple categorization as large fire events toward extreme events, measured in terms of fire behaviors, resistance to suppression and resulting impact. A key recommendation now materializing for advanced management of landscapes at risk of mega-fire is the design of control measures that are matched to specific landscape conditions. Fire management requires contextualizing to local conditions (Tedim *et al.* 2013). Any research theme must accommodate contextualization to local conditions for numerous reasons, but especially as a management strategy for contending with the extreme events that are increasingly likely to occur.

## *Oil Equivalent Energy*

Production of energy from fossil fuel sources around the globe now exceeds 10,000 million tons of oil equivalent (Mtoe)/yr (Hook *et al.* 2012). New technologies employed in the extraction of fossil fuel, such as hydraulic fracturing, or "fracking", have been disarmingly effective in meeting this growing demand. This newer stream of oil is keeping costs per unit energy relatively low in spite of growing demand. There are several cascading effects materializing from increased oil supplies emerging from the use of these new technologies. First, the development of these relatively inexpensive fossil fuel sources will continue to hamper expansion of the infrastructure needed to generate and supply energy from renewable sources. For example, projections, based on optimistic scenarios, for growth in annual output of energy from renewable sources (excluding biomass) through the first half of the 21st Century are less than 5000 Mtoe by 2050 (Shell 2008). Fossil fuel sources will continue to put energy from renewable sources at a competitive disadvantage (Freedenthal 2012). Second, technologies that maintain the advantage of fossil fuel energy will continue to produce GHG emissions, along with their cascading effects on earth systems. Third, it is now projected that specific developed countries, in particular the US, will be both the largest producers of fossil fuel energy and achieve energy independence within the next 20-30 years. In combination, these effects will likely ensure that the World's largest economy will still rely on hydrocarbons for decades to come (Miller *et al.* 2012).

## *Precision Earth*

Geospatial tools, such as GPS, GIS and remote sensing, have revolutionized most if not all aspects of the study of life on earth. Any question dealing with the issue of "Where?" can now be answered, at least in terms of its physical location, with incredible speed and accuracy. These technologies are now being applied to the generation and access of very-fine scale information and knowledge. Logically, this has been accompanied by the rapid development of highly contextualized decision-support tools for all fields, including agriculture and conservation. To illustrate, digital elevation models 30 years ago were scaled at 1/10$^{th}$ degree resolution, and today they are scaled at 1/3600$^{th}$ degree, or finer (Gallant 2011). Precision geospatial tools are routinely applied to agricultural practices, reducing costs and promoting conservation efficiencies (McConnell and Burger 2011). These developments are leading to substantive shifts in the manner in which agricultural research currently is and will be conducted (Herrick *et al.* 2013). For example, vineyard managers are utilizing open source, web-based GIS management tools in combination with wireless sensor networks supplying site specific and regional monitoring of soil and weather to conduct their own in the field management evaluations and analyses (Mathews 2013). Precision viticulture is facilitating the contextualization of general principles of vineyard management to the specifics of any vineyard; viticulturists can conduct their own research specific to their own vineyards. The release of open source precision information tools that will further facilitate this contextualization, such as the SoilWeb and JournalMap (Karl *et al.* 2012), and accelerate this emerging shift of research from academic institutions and scientific organizations to, literally, the fields of application of any discipline. These shifts are occurring without extensive software training, and in situations where the local landscape conditions, such as a small vineyard, can be adequately described and understood. Any research theme for larger landscapes inherent to rangeland and grassland management systems should accommodate and capitalize on these tools and the insights and understanding they provide.

### *Ecography*

Ecography is defined as the descriptive phase of ecology. Relative to land management, ecography emerges as ecologically based cartography. The intent of mapping ecological potential and current status of land relative to that potential is to provide a quantitative, ecologically robust, and descriptive basis for management decisions (Karl *et al*. 2012). The process of applying research results must be linked with the inherent ecological capacity of land (Peters *et al.* 2012). Ecography is meant to transparently express that capacity at scales relevant to many management decisions. In the US, one manner in which ecography manifests is the mapping of ecological sites and current or past vegetation states relative to specific ecological sites (Bestelmeyer *et al.* 2009). Ecological sites are defined as distinctive kinds of land with specific physical characteristics that differ from other kinds of land in their ability to produce distinctive kinds and amounts of vegetation. A particular vegetation state existing on an ecological site reflects the status of that site relative to its defined ecological potential to produce distinctive kinds and amounts of vegetation. . Even fine scale differences in biotic and/or abiotic attributes among sites can lead to different responses to climate and/or management, even if sites are within the same landscape (*e.g.,* Bestelmeyer *et al.* 2006, Browning *et al.* 2012). The concept of an ecological site is to parse landscapes into identifiable units that will respond in predictable manners to conservation practices (Steele *et al.* 2012). The power of ecography is that it provides a descriptive and repeatable basis to stratify landscapes in a fashion that enables hypotheses to be constructed and tested relative to effects of conservation management practices. In addition, ecography provides a framework for constructing monitoring programs that will result in data that can actually be interpreted relative to a site's responses to management. Ecography in this manner affords us the opportunity to apply experimental designs to landscapes and their management. This is a powerful tool in support of our research themes.

## Synthesis of Drivers and Externalities

Collectively, in response to such drivers and externalities there is a call for new strategies and goals for the sustainable development of our environments (Griggs *et al.* 2013). Dire predictions for a bleak future without substantive changes in policies and actions are well founded in the increasing available data points supporting assessments of resource stresses and pending catastrophic events (Holechek 2013). There is certainly a need for employing strategic thinking that is ecologically robust to guide our actions. These are serious statements that need to be heeded.

But, what are we to do? Strategic thinking is needed, but what are the tactics that can be employed to support the identified strategies? Leaders in the science community have stepped forward on all continents to shape the needed strategies. What can individual scientists and individual science programs do tactically that will be constructive?

We accept the central premise that we have to apply our science at spatial scales relevant to management (Sayre *et al.* 2012). The problems being driven by various forces have to be addressed at appropriate management scales. In this fashion our tactics are based on 2 key science behaviors from which our research theme, our basic science tactic, emerges: (1) revising our scientific method to support management by hypothesis; and (2) employing a globally informed, data intensive scientific method (Peters and Havstad, in review).

## Scientific Behaviors

### *Science in Support of Management by Hypothesis*

Recently, Sayre *et al.* (2012) called for a redirection of the dominant themes of rangeland research of the 20$^{th}$ Century. This redirection is meant to not only conduct research at larger spatial and longer temporal scales but also address more actively the heterogeneity of these landscapes in that research. This redirection is labeled a <u>post-normal science</u> (Funtowicz and Ravetz 1994) that is both practical in its objectives and interactive in engaging clients, partners, stakeholders, and the public in its conduct. At the center of this effort is the recognition of the need to build a framework for science that supports adaptive management of natural resources (Bestelmeyer and Briske 2012). We envision this post-normal science can support the concept of "management by hypothesis" in that embedding hypotheses within management decisions creates a science-based method that would truly support the "learning by doing" process called for by Walters and Holling (1990) where management and science are partners. This post-normal element of our scientific behavior is a key component of our research theme.

### *A Data-Intensive Scientific Method*

Massive volumes of data from increasingly available sources are driving new methods of data-intensive analyses (Hey *et al.* 2009, Kelling *et al.* 2009). Terms such as metadata, provenance, and cloud computing are now central to our scientific method (Michener and Jones 2012). As a result, we are seeing concerted efforts for science to be more transparent, more open, more collaborative, more interdisciplinary, and more accountable. The basic elements of the scientific method haven't changed even though it is now increasingly conducted in a "cloud". However, there is a need to revise that method so that it more clearly reflects both the demands and the opportunities created by these volumes of data (Fig. 3). Obviously, genomic research has benefited greatly from this revision to the scientific method with an increasing reliance on data-intensive analyses (Golub 2010). There are the same opportunities for data-intensive analyses influencing grassland and rangeland sciences (Peters 2010). It would, though, be inaccurate to envision these new developments as simply the result of more data leading to more complex, complete and robust analyses. At its core, this revolution is about how and which data are stored, accessed, employed and synthesized. We have always had massive amounts of data, but they have not been readily available, accessible, and/or useable. Making specific data accessible, usable and relevant to addressing key questions and problems as a normal part of our scientific behavior are also central to our research theme.

## Research Theme: "Landscape Portals"

Generalized strategies for research in dry land areas have been developed (Reynolds *et al.* 2007). However, we now have capacities to more specifically contextualize science for specific landscapes and their biophysical and human dimensions. Imagine a specific landscape, as part of a larger global network of landscapes, where that landscape is described given 5 central concepts of this larger network:

- an internet access point to all relevant data and local knowledge that can be used by a community of people (*i.e*., land owners, scientists, land managers, teachers and students, government bureaucrats, the general public) to understand, evaluate, describe and analyze this local landscape where they live and/or share interests in those lands and their resources;
- a shared basis for describing ecological potential and current ecological status of that specific landscape at scales relevant to management and conservation;
- transparent and globally accessible source data sets with geospatial specificity relevant to characterizing those landscapes and the broader influences upon their ecological nature;

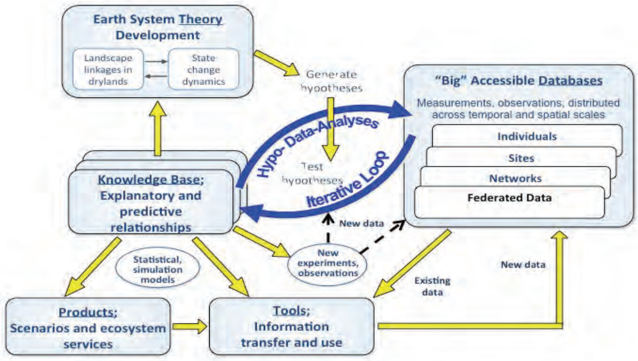


**Figure 3. The scientific method modified to incorporate existing data from global networks (from Peters and Havstad in review).**

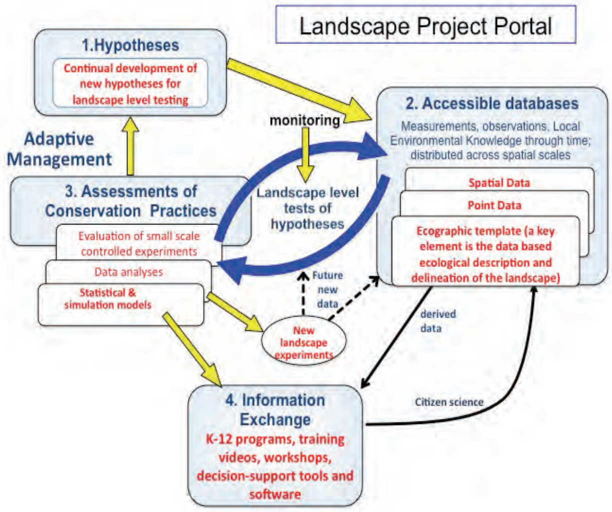


**Figure 4. The contents of a geospatial portal accessible via the Internet for a specific landscape project.**

- commonly available derived data sets that allow open and debated interpretations relative to ecographic characterizations of those specific landscapes; and
- a means whereby further information can be collected, stored and accessed for further analyses as this landscape is managed by hypothesis testing in a scientifically robust manner.

Some of these concepts have been applied to specific landscapes in the past. Some classic examples have originated out of Australia. Hinton (1995) conducted a detailed study of ecological and economic conditions of managed properties in Queensland. His analyses allowed a rudimentary assessment of factors that contributed to economic and ecological stability of the studied properties. His work was conducted at the spatial scales we think are important. However, his work lacked a quantitative, repeatable manner in which to stratify these landscapes based on key ecological features, and it lacked overall transparency. More recently, Morton *et al.* (2011) provided a framework for characterizing the ecological features of arid Australia that could provide this needed basis for stratification. However, that framework has not been directly linked to management of these landscapes or to a process that would provide the needed analyses to support adaptive management.

To implement all of these concepts, we have developed the use of geospatial portals via the Internet to contain all elements of a landscape project (Fig. 4). A portal is defined as a web page that provides access to many different sources of information on a specific theme through a single point. In addition to providing this requisite link to all elements of a landscape project, portals can be con-structed to provide secure access to levels of information deemed private within a large system of public access to non-private sources of information and knowledge.

At the centre of this landscape portal theme is our post-normal science predicated on the ability to effectively stratify the ecological heterogeneity of a landscape through the use of the concept of ecological sites. Of additional importance to this theme is the capacity of citizens to be involved in science and data collection in a structured and constructive manner. The purpose of this theme, though, is to structure and implement a scientific approach that supports adaptive management. This goal, which requires contextualizing information and knowledge to the specifics of a landscape and its environment, drives our efforts, and has caused us to redirect our scientific culture towards this theme.

Information and knowledge for specific landscapes is organized within the portal to develop management scale tests of hypotheses concerning conservation practices. The design is structured to partner management and science, and to collect relevant data from a number of global and local sources. The purpose is to create a shared basis for adaptive management (adapted from Peters and Havstad in review).

## Conclusions

Slightly over one-half of the world's land surfaces are defined as rangeland, and they are present on all continents. The pressures on these lands to be productive for numerous goods and services, but especially for food and fibre, will not abate throughout the 21st Century. These lands will be increasingly subjected to extreme climatic events as the drivers of climate change continue without relief. Despite their economic, ecological, cultural and social importance, the need to continue to draw attention to these resources as a focus for research and development will escalate as the global population continues to be increasingly urban and unconnected to these lands. We need to capture the interest of the public in the issues facing these landscapes and the science and management required to address these issues.

Technology can connect individual scientists and their science to the variety of problems manifest in rangelands over the world, in a more rapid exchange than has occurred in the past. Recognition of local challenges, innovations, and scientific tests of the effectiveness of our technological solutions to these problems can keep pace with rapid change and help us adapt to that change. We propose that in a transparent manner we directly partner science and management around specific landscapes and the conservat-ion of those landscapes. This partnership for landscape portals, where we openly conduct research in support of adaptive management, is our emerging theme that could translate to any specific landscape across the globe.

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