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Ecological services to and from rangelands of the United States

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ABSTRACT

The over 300 million ha of public and private rangelands in the United States are characterized by low and variable precipitation, nutrient-poor soils, and high spatial and temporal variability in plant production. This land type has provided a variety of goods and services, with the provisioning of food and fiber dominating through much of the 20th century. More recently, food production from a rangeland-based livestock industry is often pressured for a variety of reasons, including poor economic returns, increased regulations, an aging rural population, and increasingly diverse interests of land owners. A shift to other provisioning, regulating, cultural, and supporting services is occurring with important implications for carbon sequestration, biodiversity, and conservation incentives. There are numerous goods and services possible from rangelands that can supply societal demands such as clean water and a safe food supply. The use of ecologically-based principles of land management remains at the core of the ability of private land owners and public land managers to provide these existing and emerging services. We suggest that expectations need to be based on a thorough understanding of the diverse potentials of these lands and their inherent limits. A critical provisioning service to rangelands will be management practices that either maintain ecological functions or that restore functions to systems that have been substantially degraded over past decades. With proper incentives and economic benefits, rangelands, in the U.S. or globally, can be expected to provide these historical and more unique goods and services in a sustainable fashion, albeit in different proportions than in the past.

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1. Introduction

Rangeland is a type of land found predominantly in arid and semi-arid regions that is managed as a natural ecosystem supporting indigenous vegetation, predominately grasses, grass-like plants, forbs, or shrubs (Stoddart et al., 1975). In the United States, there are approximately 308 m ha of rangeland, about 31% of the total land area. This land type provides a multitude of goods and services not only to rural populations, but also to tens of millions of people in large urban areas located within or among rangelands. These services include food, fiber, clean water, recreational space, minerals, religious sites, and sources of natural medicines. The purposes of this paper are to: (1) describe the salient features of these lands, (2) characterize their present ownership and traditional services, (3) examine key emerging goods

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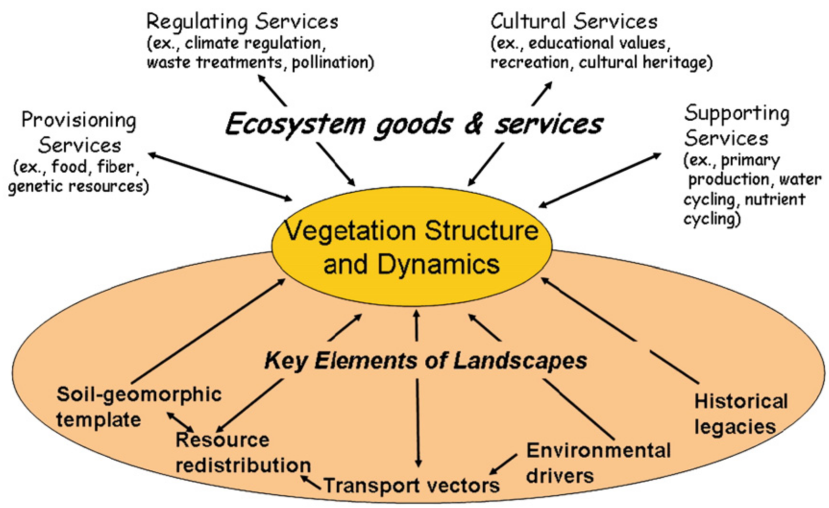

Fig. 1 – Five key elements of rangeland landscapes interact to determine vegetation structure and dynamics with resulting effects on ecosystem goods and services: (1) historical legacies of past climate, disturbances, and human activities, (2) environmental drivers, (3) transport vectors, such as the run-on and run-off of water during extreme rain events, (4) redistribution of resources, such as soil, nutrients, and seeds, (5) the soil-geomorphic template (after Peters et al., 2006).

and services that rangelands may provide, and (4) detail necessary steps, including incentives, required for a sustained delivery of any rangeland-based goods and services.

1.1. *Important characteristics of rangelands*

Rangelands are characterized by four important features which strongly influence their ability to provide goods and services. First, most rangelands are limited by water and nutrients, primarily nitrogen (N) (Hooper and Johnson, 1999). Long-term average annual precipitation is low and variable (300–500 mm/yr for semi-arid regions and<300 mm/yr for arid regions), and evaporative demand is high, often at least 95% of annual rainfall (Nicholson, 1999). Water limitation is further compounded by, and often coupled with, nutrient-poor soils. For example, N content of arid rangeland soils is often only 0.1% (Gallardo and Schlesinger, 1992), and net primary production from US rangeland averages ca. 160 $g/m^2/yr$ (Huenneke and Schlesinger, 2006).

Second, tremendous temporal and spatial variability in production characterizes these ecological systems (Lieth, 1975). Seasonal and annual variation in production is a widely recognized feature given that failure to adjust management in response to extremely low production during drought was a major contributor to land degradation in the US at the end of the 19th century (Wooton, 1908; Fredrickson et al., 1998). Given the tremendous heterogeneity in soils, landforms, and climate that occur across these landscapes, spatial variation in productivity can also be substantial (Herbel and Gibbens, 1996). Collectively, spatial and temporal variation has resulted in reports of 10-fold differences in production across years within a site and across sites within years (Ludwig, 1987).

Third, U.S. rangelands are an amalgamation of public and private ownership. For example, approximately 50% of the lands in the 14 western states are in public ownership that spans federal, state, and local governments, and a multitude of agencies and departments within those governments. In turn, these public lands indirectly influence management of private lands (Dale et al., 2000). The resulting diversity in jurisdictions, property rights, legal responsibilities, management objectives, strategic plans, and fiscal constraints has been constraining cohesive management for over two centuries. This aspect of the complexity of these landscapes is increasingly central to any discussion about the realistic capacity for rangelands to provide goods and services on a sustained basis.

Fourth, rangelands are uniquely coupled systems of both people and nature, and are commonly viewed as both complex and adaptive (Walker and Janssen, 2002). This uniqueness stems from the overriding importance of inherent ecological constraints in the management of rangelands. Dale et al. (2000) described five key ecological principles that should underlie the management of these natural landscapes: 1) processes occur within a temporal setting, 2) species can have strong effects on processes, 3) sites have unique organisms, abiotic conditions, and ecological processes, 4) disturbances are important events, and 5) landscapes affect the structure and function of local ecosystems. We have integrated these principles and complexities into a conceptual framework containing five interacting elements that both characterize the dynamic nature of rangelands and their capacity to provide goods and services, as described by the Millennium Ecosystem Assessment (2005; see Fig. 1).

Each element of our framework can directly or indirectly influence ecosystem structure and dynamics with consequences for ecological goods and services. The relative importance of these elements to ecosystem goods and services can vary in both time and space for the same system as well as among systems. In rangelands, provisioning services include food, fiber, and genetic resources, regulating services include water and air quality, cultural services include educational values and recreation, and supporting services include primary production, water and nutrient cycling.

2. Goods and services from rangelands

Agriculture is considered a precious part of cultural, social, and historical heritage in many regions, and remains highly valued as a lifestyle choice. This is certainly true for rangelands of the United States where ranching has been and continues as a central part of our collective ethos. In this expansive setting, agriculture links food and fiber production to landscape amenities, including open space, green belts, and numerous other ecosystem services.

Rangelands used for livestock production are primarily managed by cow-calf producers, or that part of the cattle industry that produces calves which are sold as young animals for fattening and finishing by the commercial cattle feeding industry. Rangelands currently supply forages that support approximately 10% of the annual feed needs of US beef, sheep and goat production, a figure that has been static or in decline through the last quarter century (USDA Forest Service, 1989). Increasingly, the rangeland livestock industry has changed in recent decades due to an escalating regulatory environment, an aging commercial rancher population, conversion of ranch properties to exurban development, low profit margins, and small individual scales of production (Fowler et al., 1993; Gentner and Tanaka, 2002; Torell et al., 2005). As a result, the U.S. cow-calf industry is highly dualistic. Almost 80% of U.S. beef cow-calf operations have fewer than 50 mother cows, and these cattle operations account for only 30% of all reproducing beef cows and heifers. Obviously, motivations for ranching are often non-monetary and include tradition, family, and lifestyle reasons. In a recent survey of the public land grazing permittees in 11 western states, Gentner and Tanaka (2002) identified two primary groups of ranchers: hobbyists and professionals, with each comprising approximately 50% of the total number of survey respondents. For all groups of ranchers, consumption motives outranked profit motives.

Livestock production could become increasingly dependent on rangelands with adjustments in approaches to production which deemphasize use of fossil fuels. Yet, the traditional supply of food and fiber provisioning services from these rangelands has been in decline. Other goods and services have emerged from this resource base. In this section we outline three prominent ecosystem services under recent discussion.

2.1. *Carbon sequestration*

Rangelands represent a vast store of carbon (C), both in soils and vegetation. Estimates are that 3.7 billion ha of rangeland and grassland globally contain 306–330 Pg of organic carbon and 470–550 Pg of inorganic carbon which is 20–25% of the global terrestrial carbon (Batjes, 1999 cited in Kimble et al., 2001) with the potential to store as much as 0.3 Gt C/y (Lal, 2004). While these numbers are staggering, it is rare to find measured rates of carbon flux in any intact rangeland ecosystem that exceed 0.10 T C/ha/y (Follett et al., 2001). Land use change, however, can have more impact on carbon stored within soils. Conversion of cultivated soils to perennial grass cover can increase soil carbon>1 T C/ha/y and carbon losses (both organic and inorganic) due to desertification (a regional degradation of resource) can exceed 1 T C/ha/y (Brown et al., 2006).

Realizing the potential of rangelands to provide regulating services through C sequestration requires simultaneously achieving three objectives: managing intact systems to increase carbon at relatively low rates, avoiding large and significant losses of C to degradation, and restoring depleted and degraded rangelands to some level of functionality.

In general, if a rangeland ecosystem is degraded due to overuse, soil carbon is lost to the atmosphere (Schuman et al., 2002). Even though rangeland soil carbon is relatively stable when soil disturbance is minimized (Follett et al., 2001), accelerated wind and water erosion can result in the loss of organic carbon at a rate up to 1 T C/ha/y over 20–25 y (Brown et al., 2006). Losses of inorganic carbon may also be significant sources of CO_2 flux to the atmosphere (Monger and Martinez-Rios, 2001). A potential pitfall in evaluating the benefits of carbon sequestration occurs when invasive and/or exotic woody plants are considered to sequester carbon. Deeper-rooting woody plants access sources of water and nutrients inaccessible to grasses, and may stimulate productivity and store carbon as wood, increasing levels of ecosystem carbon even as other ecological processes and ecosystems services degrade (Asner et al., 2004).

The greatest potential for increasing rangeland soil carbon is the restoration of degraded land or the conversion of marginal cropland to perennial grass cover (Follett et al., 2001). For example, in relatively arid New Mexico landscapes, converting mollisols with a long history of cultivation (>30 y) to perennial cover can increase soil carbon between 0.50 and 1.1 T C/ha/y for 20 y, depending on soil texture (Brown et al., 2006). Unfortunately, in arid areas where land degradation is most pronounced, there are few, if any, reliable techniques for restoration (Bird et al., 2001).

Most price estimates for carbon are below $US10/T carbon (see: http://www.pointcarbon.com for current price information). At that price, few rangeland practices could generate more than $US1/ha/y return over an extended period and many would return less than $US5/ha for long-term projects. Even large projects incorporating>10^5 ha would have to develop relatively sophisticated monitoring and verification approaches to adequately track changes due to management at an acceptable proportion of the cost. Additionally, projects of this magnitude lack the scale to escape the impact of regional variability in precipitation that could potentially prove disastrous. Aggregating large projects across regions in a portfolio approach could help offset some of the risk (King, 2002).

2.2. *Biodiversity*

Because rangelands are largely natural systems, all ecosystem services depend in some way on local biodiversity. The critical questions are 1) what causes the variation in biodiversity, and 2) how does variation in rangeland biodiversity affect particular services? Answers to the former question have often emphasized the determination of the point at which resource extraction diminishes biodiversity (Noss and Cooperrider, 1994). With regard to the second question, the relationship of biodiversity levels to ecological function has received a great deal of attention where ecosystem functions usually refer to production, decomposition, and nutrient cycling. It is generally recognized that biodiversity loss negatively affects ecosystem

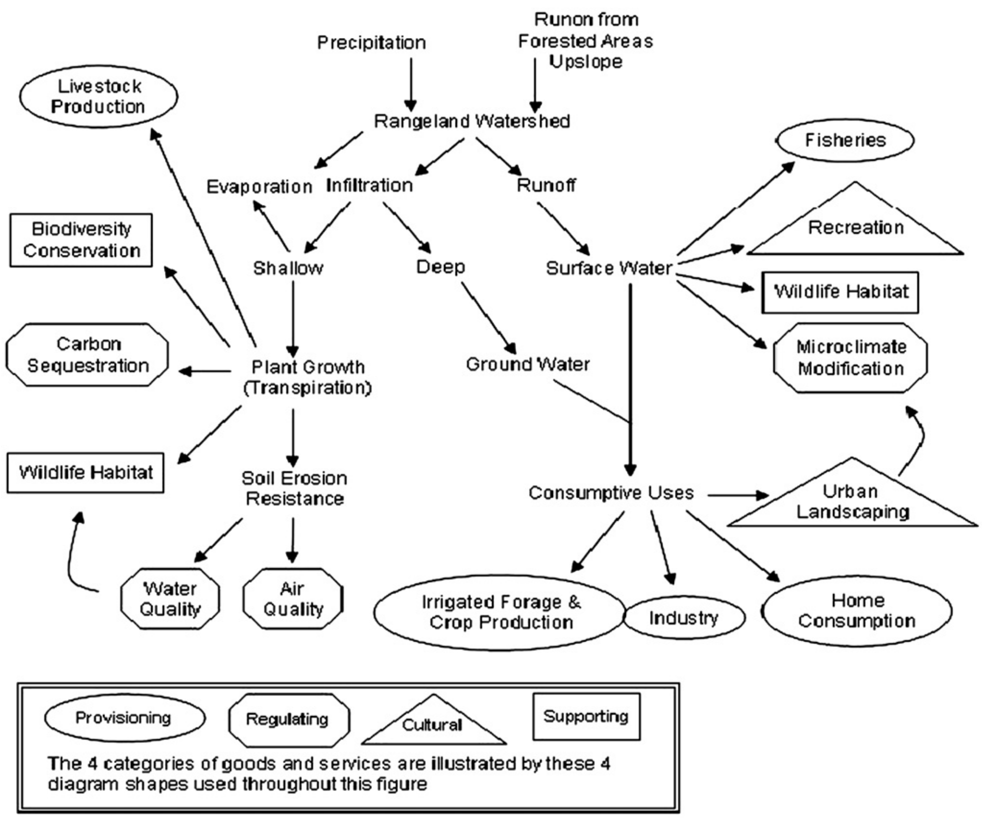

Fig. 2 – Hydrology, especially the partitioning of water among runoff, groundwater recharge, evaporation and transpiration, strongly affects ecosystem services from arid and semi-arid rangeland.

function, although the magnitude and nature of the effects on a particular function depend on traits of the species that are lost (Naeem and Wright, 2003). The functional traits that are lost, in turn, depend on their association with other traits that make species susceptible to loss (response traits).

An example of the relationship between functional and response traits in rangelands is provided by the perennial black grama grass (*Bouteloua eriopoda*) in the southwestern U.S. The growth habit and physiology of black grama allow it to stabilize erodible sandy soil, tolerate drought, and respond rapidly to pulses of erratic rainfall (Wright and Van Dyne, 1976). Because black grama maintains nutrients in its stems throughout the year, it is often preferred by livestock and tends to decline under heavy grazing (Herbel et al., 1972). When black grama declines, sandy rangeland soils erode, lose fertility, lose subsequent value for livestock production, and erosion may reduce air quality (increased dust emissions) and rates of aquifer recharge. Other grasses present in these systems do not exhibit redundancy and cannot adequately stabilize soil in the absence of black grama. Thus, black grama can be a consistent stabilizer of soil, but when in decline, rangelands dominated by this species are also vulnerable to erosion and deterioration.

In other cases, however, functional redundancy is an important safeguard preserving key services in grazed ecosystems. Grazing-induced losses of species characteristic of ungrazed ecosystems can be compensated by increases in functionally similar species (Bestelmeyer and Wiens, 1996; Tabeni and Ojeda, 2003; McIntyre et al., 2003). In still other cases, biodiversity and associated services may be resistant to, or increase with, heavy grazing (Perevolotsky and Seligman, 1998; Bestelmeyer and Wiens, 2001). Such patterns have led to the conclusion that spatio-temporal variation in grazing intensity within ecosystems promotes biodiversity and the services it provides (Fuhlendorf and Engle, 2001; Fabricius et al., 2003). Consequently, policies that promote diverse land uses (e.g., intensely grazed lands, ungrazed preserves) as well as biodiversity preservation within the context of an array of land uses might best serve humanity (Perrings and Walker, 2004). When some land uses contribute to irreversible species losses or additions (i.e., transitions) that produce an increasingly narrow range of land types (Bestelmeyer et al., 2004), homogeneity can be promoted and biodiversity services reduced. A clear understanding of species traits is necessary to anticipate changes in biodiversity services.

Over the last two decades, concern about biodiversity loss in the U.S. rangelands has shifted from the deleterious effects of poor grazing management to the loss of grazing as a land use that can promote heterogeneity (Brown and McDonald, 1995). Exurban and urban development is becoming an increasingly dominant land use in formerly agricultural areas. Natural disturbance regimes such as fires that benefit native biodiversity are difficult to maintain in exurban developments because of the risk of property loss (Hansen et al., 2005). Exurban development can reduce desirable biodiversity elements, such as native songbirds and carnivores, as well as increase non-native plant species (Maestas et al., 2003). Concern over biodiversity loss in rangelands due to exurban development, irrespective of potential improvements in some ecosystem functions, has led some ecologists and conservation biologists to promote pastoral uses and economies (Brown and McDonald, 1995; Knight 2002).

2.3. Water quality and quantity

The provision of water is the ecosystem service that most directly links growing human populations to rangelands. While forested mountains are the source of most of this water, a significant proportion is also generated by lower elevation rangelands. Much of the western U.S. is covered by hydrologically-closed basins, where water does not flow out of the basin. Rangelands on basin floors receive both runoff and groundwater from higher elevation systems as well as direct inputs from precipitation.

The relative amount available in support of ecological services depends on the quantity of water delivered to rangelands, and how it is partitioned. The partitioning of water among hydrologic processes of surface water flow, groundwater recharge, and evaporation from soils and plants depends primarily on climate and relatively static landscape properties, including topography, soil texture, and the underlying geology (Fig. 2). Land management to optimize water distribution in support of diverse ecological services in rangeland ecosystems involves multiple tradeoffs and feedbacks (e.g., Huber-Sannwald et al., 2006). Soil and vegetation management practices can have significant effects on hydrologic processes. The properties most sensitive to management include soil structure and vegetation cover, spatial pattern, and composition (Thurow, 1991). Topography can also be modified, particularly through road construction that can both impede runoff and accelerate it by facilitating gully formation. Soil and vegetation properties also affect how much of the remaining water is available for plant production, and how much is lost to evaporation from the soil and enters the groundwater. For example, shrublands lose more water to runoff than grasslands (Wilcox and Thurow, 2006; Schlesinger et al., 2000). It is generally assumed that groundwater recharge is higher under herbaceous cover than in areas dominated by woody vegetation because more water is accessed and evaporated by the deep-rooted shrubs and trees. While this pattern is generally true for non-arid systems, the effects of vegetation in arid and semi-arid systems are highly variable and context-dependent. This inherent variability has led to projections concerning possible yields from rangelands as a result of management that are not realistic (Wilcox and Thurow, 2006). Water as a supporting service from rangelands needs to be evaluated from multiple spatial scales, including watershed and basin perspectives, before we can better predict what may result under different management scenarios.

3. The primary service to rangelands-resilience, and the need for remediation

Resilience is the capacity to reorganize and provide similar functions, structures, and feedbacks in response to disturbances (Walker et al., 2004). Generally, resilience is regarded as a property of ecosystem function. However, rangelands need to be resilient if goods and services are to be provided over time. It will be necessary to ensure that these systems maintain their capacities to produce, or that those capacities are restored if they have been degraded or lost. In this sense, resilience should be viewed as the primary service that must be provided to U.S. rangelands (Walker et al., 2004). Dale et al. (2000) outlined 8 actions that work towards either maintaining or restoring site capacities: 1) examine local decisions in a regional context, 2) plan for long-term change and unexpected events, 3) preserve rare elements, 4) avoid resource depletion, 5) retain critical habitats, 6) minimize spread of non natives, 7) compensate for effects of development, and 8) implement practices that match site potential. This list of actions recognizes that rangelands are coupled systems of people and nature, and that diverse social partnerships are at the heart of successful rangeland management programs (Walker and Jenssen, 2002).

As with rangelands around the world, U.S. rangelands often have a history of degradation with or without recovery, or are at risk of degradation (Herrick et al., 1997; Reynolds and Stafford-Smith, 2002). It is increasingly understood that management of these lands has to be based on realistic descriptions of land potential (referred to as ecological site descriptions that characterize potential productivity, ecological structure, and ecological function), and often has to include restoration as an integral goal (Hobbs and Harris, 2001). Ecological site descriptions are an accepted technology that can effectively express rangeland site potentials (USDA NRCS, 1997; for example, see: http://www.nm.nrcs.usda.gov/technical/fotg/section-2/esd/sd2.html). However, these descriptions need to be completed for U.S. rangelands, a process that is underway but years from completion (Bestelmeyer et al., 2003). Properly developed ecological site descriptions have the potential both to capture key ecological processes that underlie the dynamics of particular sites, and provide a basis for quantitative indicators that can be used to monitor site dynamics over time and in response to management activities. In addition, realistic assessments of the sustainability of goods and services from these rangelands will require implementation of long-term monitoring of biotic and abiotic attributes (Havstad and Herrick, 2003). Currently, few rangelands are appropriately or adequately monitored (Brown and Havstad, 2004).

4. Steps for sustained delivery

Providing for goods and services, in any combinations of outputs, is not just a question of understanding rangeland biology and implementing ecologically-based principles for management. Sustained approaches to management also require effective linkages among land users, public and private, scientists of many disciplines, policy makers, and the public (Weibe et al., 1999; Hobbs and Harris, 2001). In order for these groups to interact effectively, they need to work from realistic expectations of these lands and to have effective incentives in support of efforts required to deliver goods and services.

4.1. Spatially explicit goods and services

The carbon sequestration case study described in Section 2.1 shows that rangelands compete poorly in markets where the ecological service of interest can be provided by other types of land and in greater quantities. For virtually all such commodities and services, inherent low productivity and high variability common in rangeland ecosystems limit their ability to compete at anywhere but the low end of the price spectrum. Perhaps the most lucrative ecological markets for rangelands are those where for specific areas the potential for certain goods and services is much more robust. For example, improving water quality within a watershed, providing habitat for endangered species, or creating open space surrounding urban areas are all services that may have relatively high value in certain locations and little or no value in others. Historically, the value of services from rangelands was determined based on the value of livestock forage produced. Their current value is driven, in large part, by their value as lifestyle locations (Torell et al., 2005).

Optimizing returns from the ecological services of rangelands depends not on enhancing methods of extraction, but rather on managing for products and services that best fit with local, regional and global needs. Realizing this goal is heavily dependent upon being able to identify markets for the diverse goods and services presented in Fig. 1, and management objectives for those diverse products.

4.2. Conservation incentives

Diverse and significant financial incentives exist for the conservation of goods and services on rangelands in the U.S. (Nelson, 1999; Weibe et al., 1999, Anella and Wright, 2004). The multiple societal and ecological benefits that landowners and public land managers provide by conserving and/or restoring wetlands, grasslands, wildlife habitats, and scenic vistas are now often being compensated in the marketplace (Wright, 1998). Although incentives are seen as servicing the private sector, rangelands are a nested public and private entity and the actions of public land managers have a direct bearing on the status of private lands. Services that were once externalities that the public expected rangeland owners and managers to provide, are now being appraised, sold or donated by private landowners. The array of tools used include USDA programs authorized under the 2002 Farm Bill. These include donated and purchased conservation easements negotiated by national non-governmental organizations such as The American Farmland Trust, Trust for Public Land, and The Nature Conservancy; agricultural easements completed by such stockgrower's organizations such as the Colorado Cattlemen's Association; and conservation easements completed by the country's over 1500 local and regional land trusts (Byers and Ponte, 2005; Gustanski and Squires, 2000; Wright 1994). To date, these combined efforts have conserved over 20 million ha of rangeland and other ecosystems in conservation easements. The total financial compensation is not public information, but it is likely to exceed $25 billion.

4.3. Land trusts

Local and regional land trusts hold conservation easements on over 2.8 million ha of private land in the United States, much of it in the arid and semi-arid West. Conservation easement agreements typically prevent residential and commercial developments and encourage on-going stewardship of natural resources by the ranchers and other private landowners. Examples are available across the West. Along the New Mexico/Arizona border, the combined actions of The Nature Conservancy, Animas Foundation, and the Malpai Borderlands Group have resulted in over 170,000 ha of rangeland being placed under perpetual conservation easements. The Gray Ranch in New Mexico forms the core of this work—a 142,000 ha expanse in a biodiversity hot spot where the flora and fauna of the Chihuahuan and Sonoran Deserts meet. The Montana Land Reliance holds perpetual conservation easements on over 243,000 ha of biologically important ranchlands, Colorado Open Lands holds 69,000 ha, the New Mexico Land Conservancy holds 21,000 ha, and the Jackson Hole Land Trust has secured 6000 ha—mostly rangelands. In the United States, local and regional land trusts close on 324,000 ha of easements per year, much of it agricultural land. The appraised value of donated easements (typically 30–70% of fee simple value) can be written off income taxes over a six-year period and can substantially lower estate tax burdens for the owners of rangeland (Byers and Ponte, 2005).

A more recent approach to the conservation of future services is limited home site development within a ranch property. The New Mexico Land Conservancy holds a conservation easement on the 12,600 ha Montosa Ranch north of the Gila Mountains. This project allowed 7 home sites to be reserved to generate income for the landowner who could be sheltered by the easement gift (Anella and Wright, 2004). This "conservation development" approach has also been used by the Heritage Land Conservancy (an arm of a private land development company) to design partial developments on New Mexico rangelands which keep the property in agricultural production.

The incentives provided by these conservation approaches demonstrate the options currently available to the owners of rangelands. Landowners may now dispassionately run the numbers on a full range of options including restoration, conservation, and development. In a real sense, an era of market-driven stewardship has emerged (Ginn 2005).

5. Conclusions

Natural ecosystems, which include the U.S. rangelands, can provide or support many ecological goods and services (Foley et al., 2005). While these lands have typically supported provisioning services during the past centuries, it is envisioned that these traditional demands will continue to diminish through the 21st century (Van Tassel et al., 2001). Rangelands are already areas that support the highest growth in U.S. employment (primarily service and manufacturing sectors). Cultural services (such as recreation, open space, and vistas) are now often the primary amenities sought (Rudzitis, 1999; Beyers, 1999). These lands are still characterized by low and variable production which greatly limits their ability to sustain delivery of any array of goods and services, traditional or otherwise. In the future, we expect to see rangelands providing an increased supply of non-traditional services, such as biodiversity, but provisioning of other services, such as significant carbon sequestration, may not be possible given the inherent ecological limits of these lands.

An essential service required to these lands will be remediation of ecological functions degraded due to misuses in the past (Herrick et al., 1997). In many cases, remediation of degraded systems or maintenance of existing systems will require application of practices based on updated understandings of the ecological site capacities of landscapes. Because many rangeland areas will not return to healthy, functioning states without intervention, their stewardship will require management by trained managers. In addition, because landscapes are often owned by an intermingled network of public and private interests (the characteristic "checkerboard" land ownership patterns that occur across the West) management actions are increasingly participatory and collaborative (Sayre, 2004; Walker et al., 2002). These actions will need to be based on a land ethic shaped by a well-founded understanding of these complex ecological systems.

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