CHALLENGES AND OPPORTUNITIES FOR ECOSYSTEM SERVICES SCIENCE AND POLICY IN ARID AND SEMIARID ENVIROMENTS

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ABSTRACT

Ecosystem services – the economic benefits that nature provides to people – are gaining recognition in the research and policy communities as a means of better supporting sustainable resource management. Yet for arid and semiarid environments, including the Colorado Plateau, research and application of ecosystem services concepts has lagged behind the more populous temperate, humid, and coastal regions of the US. Here we explore three important issues for the Colorado Plateau research and policy communities related to the ecology, economics, and geography of ecosystem services. These include: 1) the critical importance of the temporal and spatial distribution of water in supporting the ecosystems that provide these services, 2) how the location of human beneficiaries within watersheds and airsheds affects the value attributable to the ecosystem service, and 3) how low population densities contribute to long distances between beneficiaries and the ecosystems providing key services, which can reduce public perceptions of the value of these ecosystems. We elaborate on these three issues, citing examples from the Colorado Plateau and other parts of the Intermountain West, along with science and policy implications. While ecosystem services research and application toward policy are at a nascent stage on the Colorado Plateau, as this field continues to advance increased attention to these issues can advance the research agenda and identify barriers and opportunities for applying ecosystem services to decision making.

INTRODUCTION

The science of ecosystem services - quantifying and valuing the coupled ecological and economic production of the benefits nature provides to humans – is increasingly used to frame tradeoffs in conservation and economic development (Farber et al. 2006; Daily et al. 2009; Tallis et al. 2009). In recent years, interest in ecosystem services has grown among the academic, public, private, and nonprofit sectors and has potential for use in resource management on the Colorado Plateau. While several approaches exist for ecosystem services-based resource management (Salzman 2005), payments for ecosystem services (PES) programs remain the most well publicized (Engel et al. 2008). In the United States, PES has a 25-year history as part of the Farm Bill, as well as through early carbon and watershed credit trading programs. Recent Federal initiatives, including creation of the USDA Office of Environmental Markets, may provide leadership in incentivizing the protection and restoration of ecosystems and the services that they generate.

In this chapter, we argue that past research and policy applications of ecosystem services in the United States have received greater focus in temperate, humid, and coastal regions, with less attention paid to the Intermountain West and North American Desert regions, and particularly the Colorado Plateau. This situation is slowly changing (Melis et al. 2010), but there are three key issues related to the ecology, geography, and economics of ecosystem services that pose special challenges for their application in arid environments such as the Colorado Plateau.

First, we will show that water is a key driver of ecosystem services, particularly in arid and semiarid environments. For all uses,, the absolute quantity and quality of water matters greatly. Yet in addition to water quality and quantity, the specific temporal and spatial distribution of water (i.e., groundwater vs. surface water, seasonal permanence, degree of flow regulation) matters in terms of ecosystem services provision. Second, the location of different groups of human beneficiaries within watersheds (and airsheds) matters tremendously in terms of provision and use of key hydrologic services. Third, we will demonstrate the consequences to beneficiaries of ecosystem services that are sparsely distributed in the Intermountain West, particularly by contrast with densely populated eastern and coastal regions. We begin by describing the historical roots of ecosystem services, then deal with research and applications in the Intermountain West, and conclude by discussing science and policy implications in an effort to create a foundation for ecosystem services in arid and semiarid environments of the Colorado Plateau.

BACKGROUND ON ECOSYSTEM SERVICES

Although pioneering ecologists such as George Perkins Marsh and Aldo Leopold recognized the critical life-support functions played by nature as early as the late 19th-mid 20th century, the 1970s-1980s saw the emergence of modern ecosystem services conceptualizations (Mooney and Ehrlich 1997). Valuation of ecosystem services grew from the 1970s onward, as economic methods to value ecosystem services were developed and applied by environmental and later ecological economists, who produced "primary valuation" studies for locally important ecosystem services. With larger populations and more universities in coastal and humid regions, local focus on these geographic areas led to fewer ecosystem services valuation studies for western region arid lands. Thus, early efforts to synthesize this work via meta-analysis, value transfer, and the development of ecosystem services tools also took place largely outside the arid lands of the U.S. Southwest. For example, Farber (1996) completed an early synthesis of ecosystem services studies for coastal Louisiana, Villa et al. (2002, 2009) developed valuation databases and assessment tools, Costanza et al. (2006) conducted large-scale value transfer exercises at the University of Vermont, and Chan et al. (2006) and Daily et al. (2009) led development of ecosystem services mapping and valuation tools at Stanford University in California. With more primary studies to draw upon, researchers could produce more comprehensive syntheses for wetlands, forests, and coastal ecosystems (Woodward and Wui 2001; Brander et al. 2007; Zandersen and Tol 2009) than for arid and semiarid environments.

Early efforts to synthesize the valuation literature placed minimal value on semiarid and arid systems. For example, Costanza et al. (1997) gave a value of $0/ac-yr to deserts. In a more recent study, Dodds et al. (2008) assigned deserts the lowest value of six North American ecoregions. They found the value of deserts to be 1-2 orders of magnitude lower ($166/ac-yr, versus $1,879-$25,229/ac-yr for other ecoregions) than all but one other ecoregion – western forested mountains (valued at $986/ac-yr), which receive less rainfall than the eastern temperate and west coast marine forests also included in their studies. Along with having fewer primary valuation studies to work with, few past ecosystem services studies have explored the importance of services like dust regulation and its implications for human health (Richardson 2008), further underestimating their value.

The historical pattern of the arid southwestern Colorado Plateau and the Intermountain West as less researched regions in the field of ecosystem services is rapidly ending (e.g., Jones et al.2010; Norman et al. 2010; Semmens et al. 2010). The interaction between the region's historical and projected population growth, the growing strain on water, energy, and other resources, and uncertain impacts of climate change is driving research efforts and the need to apply their results toward policy. The West's abundant public land, which has historically been used primarily for extraction of ecosystem goods such as forage and timber, is increasingly recognized as a key source of other valuable ecosystem services to be managed and protected. Federal researchers at organizations like the U.S. Environmental Protection Agency (USEPA), the U.S. Geological Survey (USGS), U.S. Department of Agriculture (USDA), and others are increasing their research efforts on ecosystem services, western universities are building stronger research efforts, and university-agency partnerships are moving from investigations of ecology and hydrology toward integrated assessments of ecosystem services. Examples of these efforts can be found at USEPA's Southwest place-based research program (http://www.epa.gov/ecology/quick-finder/southwest.htm), Arizona State's EcoServices research group (http://www.ecoservices.asu.edu/), and the interagency AGAVES research effort (http://rmgsc.cr.usgs.gov/agaves/).

Researchers have explored the link between ecosystem services and net primary production (NPP, Costanza et al. 2007; Richmond et al. 2007). Similar linkages have been proposed between biodiversity and ecosystem services (Hooper et al. 2005, Balvanera et al. 2006), but in both cases these linkages and their causality are not fully understood. Ecosystems in more mesicr regions and with greater biomass could generally be expected to cycle matter and nutrients more quickly, have greater throughput of energy, and produce more ecosystem goods. From an economic perspective, however, demand must exist for ecosystem services to be valuable, and high demand (i.e., number of users) may exist in some arid regions while remaining low in humid regions that are sparsely populated. Depending on the ecosystem service, scarce services in resource-limited arid environments may have a higher marginal value than in resource-rich humid environments, although their total value could be lower if the quantity of services produced is low or where there are few beneficiaries. The importance of arid lands such as the Colorado Plateau in providing human well-being was noted by the Millennium Ecosystem Assessment (2005a), as several subglobal assessments focused on arid and semiarid regions. Finally, while highly productive ecosystems might be expected to produce more "regulating" and "provisioning" services, assuming adequate demand, there is no explicit reason why the quantity and value of "cultural" services (Millennium Ecosystem Assessment 2005b) would depend on the quantity and rate of matter, nutrient, and energy processing in an ecosystem. The spectacular natural features found in some desert environments and their historic role as "cradles of civilization" (Diamond 1997) suggests a high degree of cultural values for certain arid and semiarid lands. On the Colorado Plateau, such values are particularly important for numerous Native American cultures.

WATER AS A DRIVER OF ECOSYSTEM SERVICES ON THE COLORADO PLATEAU

Water is the primary limiting resource in arid and semiarid ecosystems, as it controls the rates and the timing of biological processes in dryland species and ecosystems (Webb et al. 2007). Prior to the development of long-distance aqueducts, food transport, and pumps capable of accessing deep

Table 4.1 Ecosystem service provided by desert aquatic habitats. The hypothesized relative quantity of ecosystem service provision, all else being equal, is indicated, with blank boxes indicating no provision, a lower-case "x" indicating low levels of provision, an upper-case "X" indicating moderate levels of provision, and a bold upper-case "X" indicating the highest levels of provision.

Ecosystem service	Unregulated streams and wetlands (perennial-intermittent flow)	Flow-regulated streams (perennial-intermittent flow)	Shallow groundwater (intermittent-ephemeral flow)	Deep groundwater (highly ephemeral flow)
Water supply	X	X	X	X
Recreation	X	X	x	x
Carbon sequestration & storage	**X**	**X**	X	x
Microclimate regulation	X	X	x	
Sediment & nutrient regulation	**X**	**X**	X	x
Aesthetic value	**X**	**X**	x	X
Other habitat-derived ecosystem services (incl. migration support)	**X**	X	x	x
Non-use value	**X**	X	x	
Hydroelectric generation		X		
Flood control		X		
Subsidence regulation	X	X	X	X

groundwater, local water availability was the critical limiting resource on human populations in deserts. Riparian ecosystems on the Colorado Plateau depend on shallow groundwater or precipitation to feed perennial (year-round), intermittent (flowing for a portion of the year), or ephemeral (flowing only in response to precipitation or snowmelt events) streams and wetlands. Even in the absence of permanent surface water, shallow groundwater can sustain riparian and wetland ecosystems that provide biological oases in the surrounding desert. Upland ecosystems are maintained by infrequent but critically important rain pulses and by snowmelt at higher elevations. Colorado Plateau uplands provide a range of important ecosystem services including carbon sequestration and storage, dust and sediment regulation, and forage provision (Miller et al. 2011).

Springs are an important type of wetland on the Colorado Plateau, which has over 5,000 named springs that have played important cultural and biological roles in this region (Stevens and Nabhan 2002). Ecological studies of desert spring ecosystems have found 100-500 times the number of species relative to the surrounding arid lands (Ferren and Davis 1991; Stevens and Nabhan 2002; Sada and Pohlmann 2003). Humans also utilize springs through diversion, irrigating pastures, channeling water to livestock, household use, and recreation. In the southern half of the Colorado Plateau, these anthropogenic activities have degraded an estimated 75 percent of the springs (Stevens and Nabhan 2002). In addition, the extraction of water tributary to springs by pumping groundwater has caused spring discharge to diminish by more than 50 percent in the majority of USGS-monitored springs on the Colorado Plateau (National Resources Defense Council 2001).

While the four Colorado Plateau states have lost a smaller percentage of their wetlands than the national average (41% vs. 53%; Dahl 1990), the rarity of these wetlands and the degradation of remaining wetlands suggests that services have been lost from these valuable ecosystems. Additionally, in many large cities within the arid Southwest, flow diversions and groundwater pumping have left dry riverbeds, which provide minimal ecosystem services (Webb et al. 2007). Since surface water permanence and flow regulation govern the biotic communities of western upland and riparian systems, they are also key drivers of the potential supply of ecosystem services (Figure 4.1; Table 4.1).

Nearly all major rivers in the American west have been impounded, impacting flow quantity and timing, water temperature, sediment and flood pulses, riparian vegetation communities, and fish migration (Stromberg et al. 2007a; Webb et al. 2007). Dams create reservoirs that can provide an array of benefits – hydroelectric power generation, flood control, and reservoir-based recreation (e.g., boating, fishing). Hydroelectric dams, including Glen Canyon Dam, have extended the length of the river-rafting season to the benefit of this user group. However, dams managed for agricultural irrigation, such as those on the Dolores and San Juan rivers, reduce the length of the rafting season by holding water in the reservoir unless irrigation delivery commitments have been met. Riparian vegetation on flow-regulated streams provides a similar basket of ecosystem services as on perennial streams. Flow regulation in the Southwest has had numerous effects on riparian vegetation structure and diversity – by creating stable flow conditions and reducing flood scour, favoring establishment of different woody species based on timing of flow releases, inundating former riparian zones within reservoirs, and diverting flows from the Colorado River Delta (Webb et al. 2007). Flow regulation traps heavy metals and other contaminants in reservoir sediments and has also provided salinity regulation

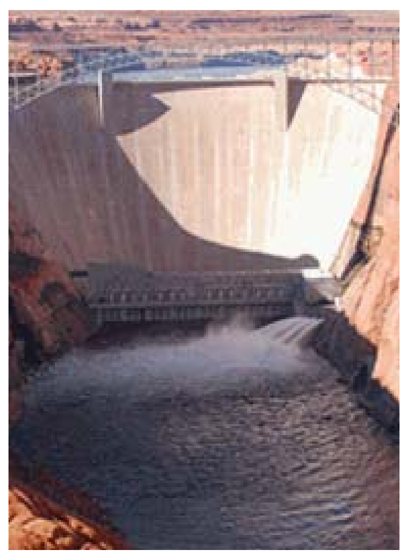
Figure 4.1 Desert aquatic habitat types

Perennial flow

Intermittent flow

Ephemeral flow (shallow groundwater)

Highly ephemeral flow (deep groundwater)



Flow-regulated river

Photo credits: Sharon Lite (Perennial, Intermittent, Ephemeral flow), Anne Phillips (Flow-regulated river) on the Lower Colorado River, as releases from reservoirs can help reduce salinity for downstream users and water delivered to Mexico. Since flow regulation can lead to the endangerment of native fishes and shifts in vegetation and avian communities, certain habitat-derived ecosystem service values will differ in these systems (Osmundson et al. 2002; Stromberg et al. 2007b; van Riper et al. 2008).

The headwaters and smaller tributaries of many rivers originating on the Colorado Plateau have perennial flow, including Oak Creek, the East Verde, Tonto Creek, Nankoweap Creek, Clear Creek, and others. Consistent precipitation and snowmelt, along with shallow bedrock depth are important in maintaining perennial flow in these streams. In addition to providing water, perennial streams provide certain recreational benefits (i.e., rafting, fishing). Given their rarity, they may also have non-use value; that is, a value held by people who may never visit the ecosystem or derive direct benefit from it, but who value its continued existence and the right to pass it on to future generations, or the option to use the resource differently in the future (Bishop et al. 1987). Most importantly, unregulated perennial streams are more likely to support greater vegetation cover, species diversity, and native species dominance (Stromberg et al. 2005), which can combine to lead to greater carbon sequestration and storage, cooler microclimates, trapping of sediment and absorption of nutrients, greater aesthetic values, and other habitat-derived ecosystem services (e.g., wildlife watching).

Streams with intermittent flow like the Little Colorado River, Kanab Creek, and Paria Creek provide similar services. The major difference between perennial and intermittent flow streams is typically the loss of riverine marshland near the active channel, as these plants require permanent flow and shallow groundwater to survive, and a shift in the dominance of tree species from more hydric to mesic species (e.g., from cottonwood-willow to tamarisk, Russian olive, and mesquite; Stromberg et al. 2005). Functionally, intermittent and ephemeral streams provide many of the same habitat and recreational benefits that are found along perennial streams, with the exception of those services depending on the presence of permanent surface water, riverine marsh, and cottonwood-willow vegetation types. In addition, intermittent and ephemeral channels are an important source of groundwater recharge because when water does flow during storm events it can recharge floodplain aquifers. Mountain-front recharge, which includes recharge from the mountain block system and stream channels, is considered to be the most significant form of groundwater recharge in arid and semiarid regions, but recharge in ephemeral stream channels also makes up a significant portion of the total (Goodrich et al. 2004; Coes and Pool 2005).

In regions where groundwater pumping, surface-water diversions, or naturally deep bedrock in low desert environments create ephemeral flow conditions, a lower diversity, less vegetated riparian ecosystem is often present. These conditions are also found in desert washes, which never had permanent flow but are still oases of productivity relative to the surrounding desert. Phreatophytes such as tamarisk and mesquite may still be able to access groundwater, providing greater and more seasonally permanent vegetation cover than the surrounding desert. These species still provide key ecosystem services, including carbon sequestration and storage, sediment regulation, groundwater recharge, and habitat-derived ecosystem service values. However, in the absence riverine marsh and shallow-groundwater dependent phreatophytes like cottonwoods and willows, the ability of ephemeral streams to provide services like aesthetic values and microclimate regulation is typically less than for rivers with greater surface flow

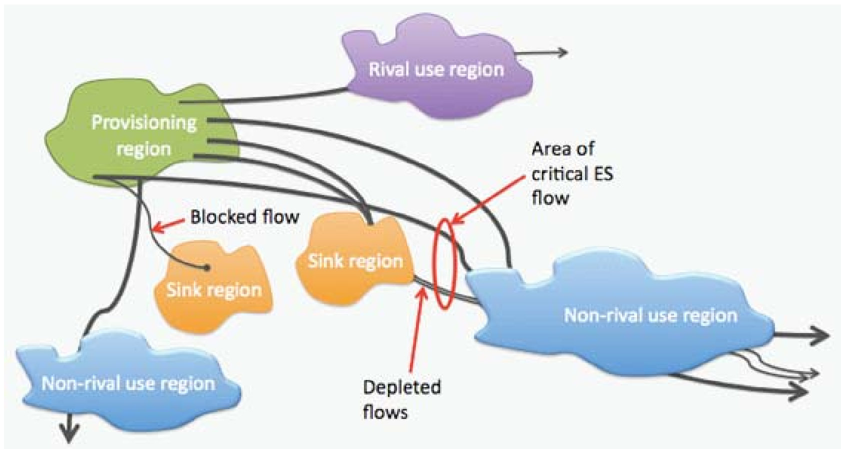


Figure 4.2 Spatial dynamics of ecosystem services. Sink regions are areas that block or absorb a matter, energy, or informational carrier of an ecosystem service (i.e., areas that absorb flood water, sediment, or nutrients or visual blight that degrades a high-quality view of nature). Sinks or rival use of an ecosystem service carrier deplete the carrier quantity while non-rival use does not (Johnson et

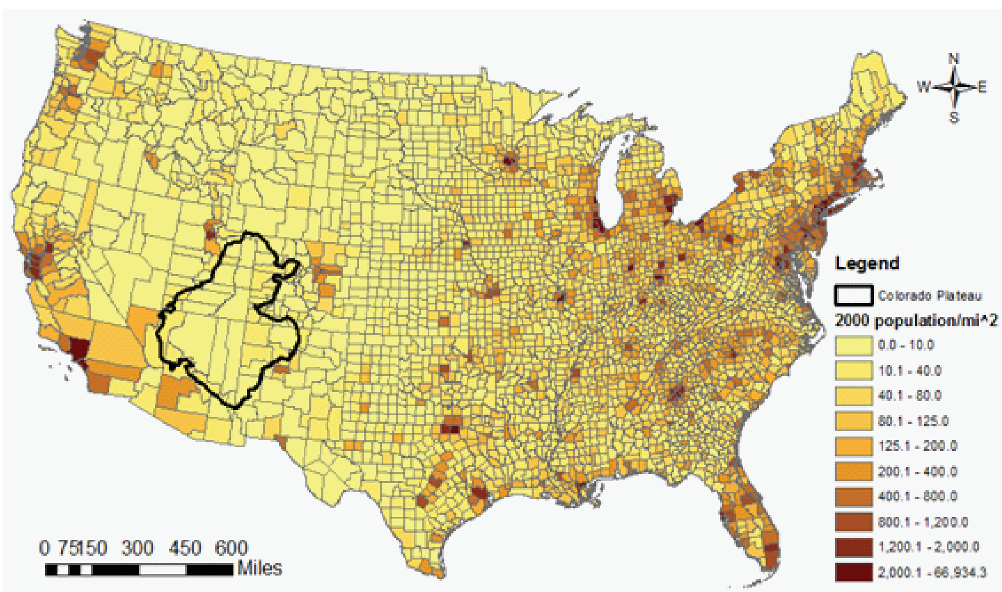


Figure 4.3 Continental U.S. population density by county.

permanence (Hultine et al. 2008).

As groundwater is pumped from deeper and deeper depths, often in excess of natural recharge rates, the riparian system eventually collapses leading to the loss of nearly all phreatophyte plant cover. Such dewatering has been the norm in low deserts near population centers like Phoenix (Salt and Gila Rivers) and Tucson (Santa Cruz River) and also on the Colorado Plateau in regions subjected to diversion projects, such as Kanab Creek in Utah.

These water-related ecosystem service issues raise a paradox: while deep groundwater may still be available for human use in highly flow regulated or dewatered systems, it is the presence of shallow groundwater or seasonal to permanent surface water that is critical for generating ecosystem services. Unregulated, permanent surface water is one of the scarcest resources on the Colorado Plateau and elsewhere in the Intermountain West, potentially increasing the marginal value of the services generated by these systems. It has been common in the West to appropriate all water for irrigation, domestic use, or mining, and to impound rivers for flow regulation, flood control, hydroelectric generation, or water supply regulation such as was done with the Glen Canyon Dam. In many cases ecosystem services have been lost as a result of these decisions. By ignoring the benefits of ecosystem services, society has come to solutions to the macroallocation problem: "how much ecosystem structure [e.g., water] should be apportioned toward the production of human-made goods and services and how much should be left intact to provide ecosystem services?" (Farley 2008). Long-term economic flows of recreation, aesthetics, habitat-derived ecosystem services, and some regulating services (Table 4.1) have been traded off to satisfy an immediate perceived need for water. Western water law and settlement policies encouraged this through policies of "first in line, first in right" and "use it or lose it" (Glennon 2009). Surface flows, however, are the first thing to go, after which there may still be a relatively large amount groundwater to pump. By recognizing that different types of aquatic systems provide different baskets of ecosystem services with different values, society could better recognize these trade-offs, ideally informing better water management.

THE IMPORTANCE OF WATERSHED AND AIRSHED POSITION

The preceding discussion of ecosystem service provision by desert riparian and wetland ecosystems dealt only with the potential provision of ecosystem services. Ecosystem services are an inherently anthropocentric concept: without demand for a service, or clear human beneficiaries, there is no ecosystem service (Ruhl et al. 2007). Much of the spatial modeling of ecosystem services that has taken place in recent years has accounted only for the potential provision of ecosystem services (Eade and Moran 1996; Nelson et al. 2009; Raudsepp-Hearne et al. 2010), with minimal attention paid to the location of beneficiaries in relation to the ecosystems providing the service and the temporal and spatial flow characteristics for that service (Ruhl et al. 2007; Fisher et al. 2008; Tallis et al. 2008; Johnson et al. in Press).

In many situations where the benefits of watershed-based ecosystem services were large and obvious and the beneficiaries nearby, ecosystem services-based management took place well before the concept of ecosystem services was recognized. Cities like San Francisco, New York, Seattle, and Portland protected their watersheds in order to avoid the costs of water filtration and purification (Chichilnisky and Heal 2000; Patterson and Coelho 2009), while in Hawaii watershed protection was undertaken to maintain agricultural water supplies especially for sugar cane. Many of these decisions were made a century ago or more. Contemporary

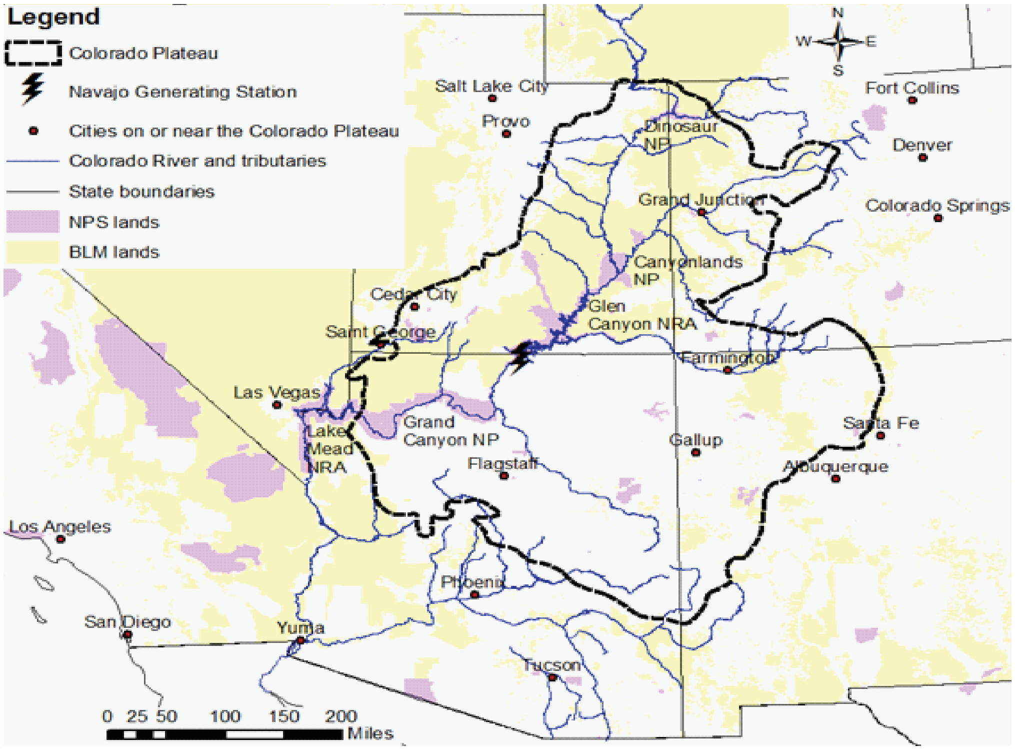


Figure 4.4 The Colorado Plateau and locations important to ecosystem services supply, demand, and spatial flows.

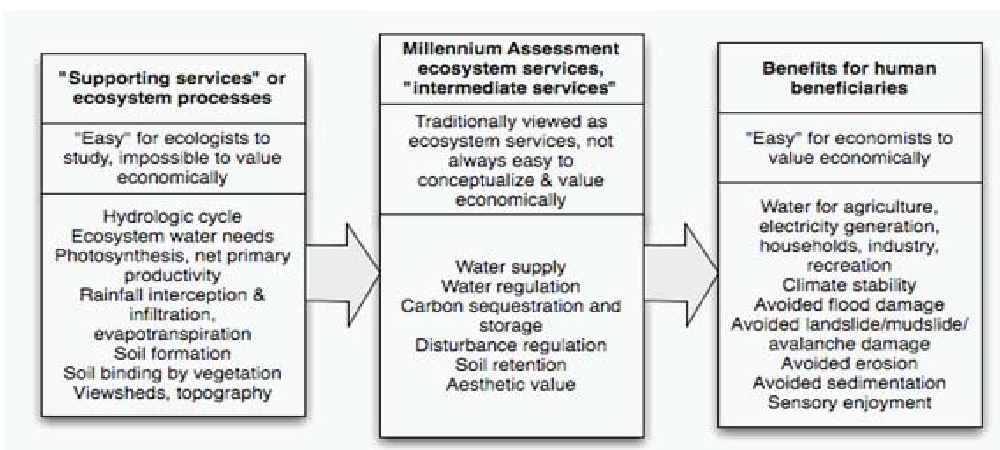


Figure 4.5 A beneficiaries-based conceptualization of ecosystem services.

examples such, as Quito, Ecuador where a watershed protection fund was created (Echavarria 2002), and similar payment for ecosystem services (PES) programs in Latin America, demonstrate that the PES concept can be quite powerful when there are large downstream cities with much to gain from protecting land surrounding their water supplies.

Similar decisions have taken place in arid regions. Theodore Roosevelt established the Tonto National Forest for watershed protection purposes in 1905, when downstream Phoenix's population was less than 10,000 residents. Today the Tonto plays a critical role in watershed protection for the Salt and Verde Rivers, which supply 54% of Phoenix's current water supply (City of Phoenix 2005). Other large western cities similarly derive water-supply benefits from open space: Flagstaff from the Coconino National Forest, Salt Lake City from the Wasatch Range managed by Salt Lake County and the U.S. Forest Service, Tucson from the BLM's Las Cienegas National Conservation Area and other protected lands on the Sonoita Plain, and Denver and other Colorado Front Range cities from national forests along the Rocky Mountains. These "spontaneous" uses of ecosystem services in land management took place when the benefits from ecosystem services were large and the beneficiaries obvious and transparent. However, these cases do not necessarily demonstrate new ways forward for ecosystem services-based management when the beneficiaries and benefits are less obvious – where beneficiaries are distant and/or not located in the downstream portion of a watershed or airshed. In the sparsely populated Intermountain West, where downstream beneficiaries are few or are located a far distance away, this may be the norm rather than the exception to the rule.

On the Colorado Plateau, researchers and managers are increasingly recognizing the importance of accounting for provision and beneficiaries (supply and demand) of ecosystem services and their spatial and temporal flow patterns in preparing rigorous assessments of the managed landscape. For hydrologic services (i.e., water regulation and supply, flood, sediment, and nutrient regulation), the location of human beneficiaries within a watershed matters tremendously. The flow of surface and groundwater carries the benefit of water (or avoided detriment of flood water, excessive nutrients, sediment, or pathogens) toward human recipients. The ecosystem service is the provision of a beneficial carrier (i.e., water supply in surface or groundwater) or the prevention of a detrimental carrier (i.e., absorption of flood water, sediment, nutrients, or pathogens; Johnson et al. in Press) from the landscape to people within that ecosystem. Thus, if beneficiaries are physically located downstream from an ecosystem providing a benefit, there can be high ecosystem service value, particularly in arid regions where water is scarce. If there are few to no downstream human beneficiaries, there is likely minimal economic value associated with these ecosystem processes (Figure 4.2). Similarly, the location of people and recreation sites such as the Grand Canyon within airsheds dictates the value of dust and noise regulation: without human beneficiaries, values are likely to be low, while the presence of a large number of beneficiaries is likely to yield higher values (Schulze et al. 1983).

The arrangement of water users and supplies in the Southwest has evolved dramatically over the last century and is likely to continue to do so in the future. Initially, the movement of water through interbasin transfers and agricultural irrigation canals, accompanied by regulation of flows from dam construction, brought water to burgeoning southwestern cities and agricultural lands while reducing flows to the Colorado River Delta in Mexico. This spatial reallocation of water and NPP across the

Southwest has provided ecosystem services to the region's cities and agricultural lands while at the same time reducing them in the delta and along low desert rivers such as the Santa Cruz, Salt, and Gila rivers. Climate change, water availability, and demographic trends, all influenced by the national and regional economy, will continue to influence population trends in the Southwest in coming years, also influencing allocation of water and ecosystem services.

LONG-DISTANCE BENEFICIARY FLOWS

Like the case where precipitation from the Rocky Mountains ultimately provides water to distant Los Angeles, Las Vegas, Phoenix, and Tucson, low population densities in the Intermountain West mean that spatial flows of ecosystem service benefits often cross long distances, particularly relative to densely settled coastal regions (Figure 4.3). Census Bureau population density estimates of the Intermountain West states (Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Utah, and Wyoming) in 2010 were 25.8 persons/mi2, versus 87.3 persons/mi2 for the U.S. as a whole and 135.6 persons/mi2 for states outside the Intermountain West and excluding Alaska. Population density on the Colorado Plateau is even lower, with 11.2 persons/mi2 estimated to be living in counties on the Colorado Plateau.

Important examples of long-distance beneficiary flows on the Colorado Plateau include: 1) the dependence of downstream cities on upstream snowpack and land-use practices as they affect water quality and quantity (e.g., residents of Los Angeles, Phoenix, Tucson, and Las Vegas depend on Colorado snowpack that feeds the Colorado River reservoirs); 2) migration-derived ecosystem services (Semmens et al. 2011) that cross the continent; 3) recreation and non-use values for charismatic species and landscapes (e.g., iconic western species and national parks) that are valued by Americans and international visitors; 4) impacts of dust transport on Rocky Mountain snowpack and Colorado River runoff (Painter et al. 2010). For rare but poorly-known species, ecosystems, or places it can be difficult to reconcile low estimates of willingness to pay (particularly for non-use value) with the greater value attributed to equally rare but otherwise better known resources. For instance, Brookshire (University of New Mexico, Albuquerque, New Mexico, personal communication) found steep distance decay in willingness to pay for non-use values for southeast Arizona's San Pedro River, likely in part because it is not a nationally-known resource like some of the well-recognized national parks on the Colorado Plateau. Distance decay functions may be much less steep for charismatic species or sites, and must be taken into account when aggregating estimates of willingness to pay (Pate and Loomis 1997; Loomis 2000; Bateman et al. 2006). For example, visibility and quiet in national parks like the Grand Canyon is highly valued not just by visitors but by Americans at large, indicating substantial non-use value (Schulze et al. 1983). These values played a role in the decisions to limit helicopter overflights of the canyon and to upgrade pollution control at the nearby Navajo Generating Station, which has improved wintertime visibility in the park (Green et al. 2005).

Low population densities and long-distance beneficiary flows present several challenges to ecosystem services valuation on the Colorado Plateau. All else being equal, smaller beneficiary populations should lead to less demand for and value of an ecosystem service. However, long-distance beneficiary flows can lead to underestimates of ecosystem service values in two ways. First, a lack of public awareness, and hence value may be placed by the public on distantly-derived ecosystem services. Second, economists may aggregate values over an inappropriately small number of beneficiaries relative to those who actually derive benefits from the services. This illustrates the potential value of new tools to map the full extent of provision, beneficiaries, and spatial flows of ecosystem services (Johnson et al. in Press): for both economists doing survey work, to make sure they survey and aggregate results across the entire beneficiary population, and for survey respondents, for whom awareness of their dependence on distant ecosystems for economic benefits must be raised to make informed decisions. For decision makers, ignoring certain beneficiary populations can lead to underrepresentation of key stakeholders in decision making, leading to less equitable choices, such as the early-20th century decision to under-represent the value of Colorado River flows to Mexico and the Colorado River Delta.

Two examples from the Colorado Plateau illustrate the importance of considering the watershed and airshed position of beneficiaries across long geographic distances (Figure 4.4). First, rising energy costs and increasing demand for domestic energy sources is leading to renewed interest in oil shale and tar sands development in the Upper Colorado Basin, and uranium mining on the north rim of Grand Canyon National Park (Alpine 2010). Many of these proposed extraction areas are on BLM land adjacent to or upstream of national parks including Canyonlands and Dinosaur, and Colorado River reservoirs including Lakes Powell and Mead. The high water demand associated with oil shale and tar sands development, coupled with associated land disturbance and water pollution, could potentially impact recreational, water supply, and non-use values for a large number of distant beneficiaries (BLM 2008, http://www.blm.gov/wo/st/en/prog/energy/oilshale_2.html).

A second example links land use to Rocky Mountain snowpack and regional water supplies via regional dust transport. Recent research has linked grazing history and the presence of biological soil crusts and perennial grassland plants to the amount of dust generated during windstorms (Painter et al. 2010; Miller et al. 2011). Sites with a long history of grazing or off-road vehicle use can act as sources of windblown dust, which can then cause faster snowmelt of the Rocky Mountain snowpack due to decreased albedo. Models of dust transport, snowmelt, runoff, and evapotranspiration suggest that dust loading may be responsible for an approximately 5% reduction in runoff in the Upper Colorado Basin (Painter et al. 2010). For dispersed downstream water users both on and downstream of the Colorado Plateau, maintaining the dust regulation service provided by Colorado Plateau rangelands would produce substantial benefits in water supply, human health (Richardson 2008), and other ecosystem services. Doing so will require improved public awareness, political will, scientific capacity, and institutions to manage resources on the Colorado Plateau.

IMPLICATIONS FOR SCIENCE AND POLICY

Scientific implications

Aside from recreational values and ecosystem goods, ecosystem services on the Colorado Plateau have rarely been quantified for either upland or aquatic systems. Emerging tools to map and quantify ecosystem services offer a way forward in comparing resource management tradeoffs. Incorporating locally relevant ecological and hydrologic process models within an ecosystem services assessment and valuation framework is a shared goal of many of these modeling tools, and would substantially improve the scientific validity and managerial relevance of these efforts. Their initial development must account for locally relevant ecological processes and economic preferences over the Colorado Plateau. A forthcoming USGS review of ecosystem services mapping and valuation tools is intended to inform public land managers as to the ability of these tools to quantify and value ecosystem services, thus adding value to established agency decision-making processes (Bagstad et al. in Press).

Further research on ecological and economic production functions related to ecosystem services provision would improve our understanding of how services are produced and valued across all ecosystems (Nelson et al. 2009), including those on the Colorado Plateau. Two other recent trends in ecosystem services research – a move toward recognizing services as concrete, spatially explicit benefits (Boyd and Banzhaf 2007; Wallace 2007) rather than abstract classes of ecosystem services (Millennium Assessment 2005b), and the mapping of provision, use, and spatial service flows (Johnson et al. in Press), offer a path forward in addressing the challenges of beneficiary locations and long-distance benefit flows to ecosystem services applications on the Colorado Plateau. A move toward a beneficiary-focused framework for mapping and valuing ecosystem services can help to avoid double counting of ecosystem services, while more clearly identifying different values held by various beneficiary groups (Figure 4.5). The "static value maps" (Tallis et al. 2008) that have predominated recent ecosystem services literature (e.g., Eade and Moran 1996; Nelson et al. 2009; Raudsepp-Hearne et al. 2010) often fail to account for areas where services are provided, used, and the spatial flow characteristics that connect these regions of provision and use. As such these maps typically better represent potential provision of an ecosystem service, rather than its actual use. While work is underway to fully map spatial dynamics of ecosystem services, in the interim, static maps often remain more feasible to generate in the absence of support to further develop case studies of ecosystem service flows.

Recent advances in conceptualizing ecosystem service flows (Semmens et al. 2011) can better inform stakeholders and beneficiaries ranging across wide distances as to their spatial dependencies on ecosystems, while ensuring that benefits are aggregated correctly (Figure 4.2). Relevant long-distance flows on the Colorado Plateau include water supply, dust regulation, migration-derived services, aesthetics, recreation, and non-use values. A full understanding of spatial flow dynamics also allows planners to make better decisions about spatial planning of conservation, restoration, development, and extractive resource use – by avoiding or targeting activities that protect ecosystem services and enable their spatial flow to beneficiaries. With a full view of beneficiaries and regions that reduce or enhance service provision, maps of the spatial dynamics of ecosystem services over the Colorado Plateau can provide guidance on structuring economic incentives to promote more sustainable management and use of ecosystem services, such as polluter pays versus beneficiary pays approaches to PES programs.

Policy implications

The difficulty of linking water quantity, quality, location, and timing to ecosystem service provision, watershed position, and long-distance beneficiary flows partially explains why ecosystem services to date have failed to impact watershed management decisions over the Colorado Plateau on a meaningful level. Ecosystem services like outdoor recreation are relatively easy to include in traditional economic assessments. Yet the reason for this chapter and the promise of ecosystem services assessments lies in reframing decision making, particularly on public lands in the Western United States, as more than just a tradeoff between recreation and resource extraction. This issue will continue to grow in importance as population growth, climate change, and demand for domestic energy development place increasing strain on natural resources, and as Federal agencies continue to explore the ecosystem services paradigm as a way to better balance public lands management for both private and public goods.

For managers, ecosystem services provide more information about stakeholders that can be incorporated into resource management decisions. Public lands supply numerous ecosystem services to beneficiaries ranging from local to global scales, and are themselves impacted by upstream management practices. A more sophisticated understanding of who these impacts influence can provide better management guidance. While managers may be accustomed to thinking about movement of wildlife and visitors within protected areas, methods to visualize and map other ecosystem services can offer additional means of engaging new stakeholders and adjacent landowners that influence ecosystems and ecosystem services.

Improved accounting for the spatial dynamics and beneficiaries of ecosystem services is an important step in bringing ecosystem services into policy. Yet since most ecosystem services are not market goods, they require institutions to manage them, through alternative means such as assignment of property rights, extraction quotas, market structures, and social norms for common-pool resource management (Ostrom et al. 1999; Salzman 2005). Western institutions were historically created to facilitate settlement and resource extraction – from 19th century homesteading and mining laws, to modern water law, to the use of state trust lands for funding public education. Recent decades have seen major Federal landowners like the BLM and the US Forest Service move from "multiple use-sustained yield" toward an "ecosystem management" paradigm to better balance extractive resource use with other benefits derived from public lands. The Glen Canyon Adaptive Management Program is a recent example from the Colorado Plateau that seeks to maintain and enhance ecosystem processes and services of the Grand Canyon by changing operations of Glen Canyon Dam (Melis 2011). Yet typical western patterns of land ownership – divided between Federal, state trust, and private land – many times intermixed in a checkerboard pattern – rarely facilitate easy environmental management and will require continued coordination of multiple actors to maintain ecosystem service flows.

Institutions can help foster trust, bring Native American tribes and small landowners into new incentive systems, spatially target incentives, and monitor and verify gains in ecosystem services provisioning. In the United States, perhaps the longest running ecosystem service-based institution pays farmers to provide environmental benefits, dating to the 1986 Farm Bill. The recently created USDA Office of Environmental Markets seeks to develop the standards and infrastructure for market-based conservation. Western farms and ranches are generally larger than the national average but have lower productivity on a per-acre basis, which may mean lower ecosystem services production, depending on their location and number of ecosystem service beneficiaries. Quantification of services is thus important, and potential value matters relative to "opportunity costs," the potential economic return from an alternative extractive resource use. For instance, if the provision of carbon sequestration or other commoditized ecosystem services are lower in arid regions, will incentives for carbon sequestration really help ranchers improve their management practices (de Steiguer 2008)? The answer to this question depends on quantifying service values and opportunity costs, developing institutions to facilitate ecosystem services-based management, and disseminating these concepts beyond academia.

Finally, while there is currently great interest in valuing ecosystem services, it is not always appropriate or possible to value services in monetary terms (USDA 2008). While dollar values provide a common currency, shoehorning all public preferences for the environment and ecosystem services into dollars or a cost-benefit framework should not be the only goal of ecosystem services research and policy on the Colorado Plateau. Non-monetary estimates of value or preferences may be highly appropriate for some values (e.g., Native American cultural values), less controversial than using dollars in other cases (e.g., endangered species), or useful and well established alternatives to economic approaches in some fields (e.g., recreation management).

To bring ecosystem services into decision making on the Colorado Plateau, further evolution of their underlying science and policy is needed. However, the needed conceptual frameworks, spatial models, and policy tools are rapidly developing and offer promise for enhancing resource management both in general, and for the unique cultural and biological resources of the Colorado Plateau.

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