Ecosystem Services and Damage Costs of Federal Lands: A Case Study of Gila National Forest, USA

Aspen Manning and Jason P. Julian*

Department of Geography, Texas State University, San Marcos, TX 78666

**Corresponding author:* Email: abj1@txstate.edu

Abstract

Protected lands provide a wide range of ecosystem services and other benefits to multiple stakeholders across all scales, from local to global. This paper uses Gila National Forest (New Mexico, USA) as a case study to show the value of these ecosystem services and the damage costs associated with removing its protection from development. Total values for ecosystem services ranged from $2.2 – 2.5 billion annually. Damage costs from development of just 1.4% of Gila National Forest's total area were $82 – 273 million. By using readily available data and simple analyses, this study illustrates the importance and value of ensuring that federal lands remain protected.

Keywords: *Gila National Forest, ecosystem services, federal lands, protected places*

1. Introduction

Recently there has been a push from the federal government, lawmakers, and development interests to transfer some USA federal lands to state and local entities (Eilpern 2017a). This transfer would make it easier to sell the lands to private owners, removing protection from development and/or public access (Herring 2016). In February 2018, Bears Ears National Monument and Grand Staircase Escalante National Monument were dramatically reduced in size, primarily to allow development of mineral resources. Bears Ears was cut to 16% of its original size and Grand Staircase Escalante was reduced by about half (Nordhaus 2018). Though this movement has been met with resistance from stakeholders (Herring 2016) and outdoor retailers (Fears 2017), the possibility of transfer of more federal lands to states and private interests (or at least removal of protections) still looms. Tensions between stakeholders and state/federal authorities continue to run high (Heild 2016).

There are also instances where federal lands in the West are traded for other lands or sold to fund other priorities. These types of transactions are authorized by the Federal Land Transaction Facilitation Act (FLTFA), which was permanently reauthorized in March 2018 (The Conservation Fund 2018). While land swaps associated with the FLTFA may not change the total protected area, they may change the land use, conservation needs, and/or overall function of the protected area. When these transactions take place, an important question is how will the trade-offs associated with the transfer of protections from one parcel of land to another affect the total value of the system, beyond just price per acre.

If federal lands are swapped, transferred out of public ownership, or just unprotected, then the

public could lose some of the ecosystem services provided by them. Ecosystem services (ES) are the benefits that humans receive from ecosystem processes and functions (Costanza, et al. 1997), and they are a vital part of the broader social-ecological system where people and ecosystems are linked through feedbacks with an adaptive capacity (Berkes and Folk 1998). Understanding the value of these benefits and the trade-offs associated with management decisions is important to their conservation (TEEB 2010). While not an ideal practice for conservation ecology (Wilson 2016), placing monetary value on ES makes nature's values "visible" to policy-makers and the public so that they understand the need for protection.

This paper is a case study on the monetary value of ES provided by a prominent federal land, Gila National Forest in New Mexico, USA. Gila National Forest (GNF) was chosen for this case study because: (1) it is under threat from both environmental and policy changes; (2) it provides a diversity of ES; and (3) it is home to the first officially designated USA Wilderness Area, Gila Wilderness. This designation was a result of the work of Aldo Leopold, a Forest Service employee who designated the Wilderness Area to discourage road construction through the sensitive environment (Williams 2005). Leopold argued for the preservation of untouched forest land, in part to preserve the option value of the land for future use (Schneider-Hector 2009). Though Leopold was referring to future timber supplies, this wilderness preservation also maintained biodiversity and important ecosystem functions. Protecting wilderness areas from future development guarantees a certain level of well-being, as well as buffers for unforeseen impacts from global changes in technology, land use, and climate (Wilson 2016; Bartkowski 2017).

2. History and Geography of Gila National Forest (GNF)

Gila National Forest became designated as a National Forest in 1899 (USDA 2016), following government efforts to set aside forest reserves for the management of timber and other natural resources. After 1900, the focus shifted to recreation and conservation of national forests (Williams 2005). Gila Cliff Dwellings National Monument (GCDNM), which makes up 216 ha of GNF, became designated as a National Monument in 1907 in order to protect the cultural resources found within it (Russell 1992). In 1924, the Forest Service established the nation's first designated Wilderness Area, Gila Wilderness (226,000 ha), in the forest (USDA 2016). Two additional Wilderness Areas, the Aldo Leopold (82,000 ha) and Blue Range (12,000 ha) Wilderness Areas were designated in 1980.

Gila National Forest is comprised of 1.3 million ha of arid and semi-arid forest and grasslands. The southernmost portions of GNF are part of the Madrean Archipelago, a group of mountain-top 'sky islands' surrounded by desert shrub and grasslands located throughout the southwestern USA and northern Mexico. The climate of GNF is marked by four distinct seasons and is dependent on the North American Monsoon, which occurs in late summer and is typically followed by and preceded by periods of drought (Douglas et al. 1993). The vegetation of GNF ranges from grasslands and Chihuahuan Desert scrubland or chaparral at lower altitudes, pinyon-juniper woodlands at mid-slope, and ponderosa pine-dominated forests at higher altitudes. Spruce-fir forests can be found at the highest elevations (Boucher and Moody 1998; Shaw 2008). Though grasslands are abundant in GNF, 88% of the landcover is forest and woodland (Shaw 2008). The Forest Service has prioritized the control of three invasive exotic plant species in GNF: bullthistle (*Cirsium vulgare*), saltcedar (*Tamarix spp.*), and yellow starthistle (*Centaurea solstitialis*) (Forest Service 2017).

GNF contains innumerable intermittent creeks and three major perennial rivers. The Gila, San Francisco, and Mimbres Rivers all have their headwaters in GNF, with a majority of their runoff recharging regional groundwater basins. The Gila and San Francisco Rivers also provide drinking water to Native American tribes and municipalities in Arizona upstream of their confluence with the Colorado River. No major dams or reservoirs are located within GNF.

The Forest Service controls the resources in GNF, including the Wilderness Areas; the National Park Service manages GCDNM. Land uses in GNF include recreation, rangeland, and timberland. Much of the land used for recreation is also used for timber harvest (Figure 1), grazing, or both. The forest had 109 allotments for grazing available for 2017 (Forest Service 2017), for which the Forest Service collected grazing fees (Torell and Drummond 1997). A few small residential communities are located within and around the forest, but overall GNF is isolated from urban areas.

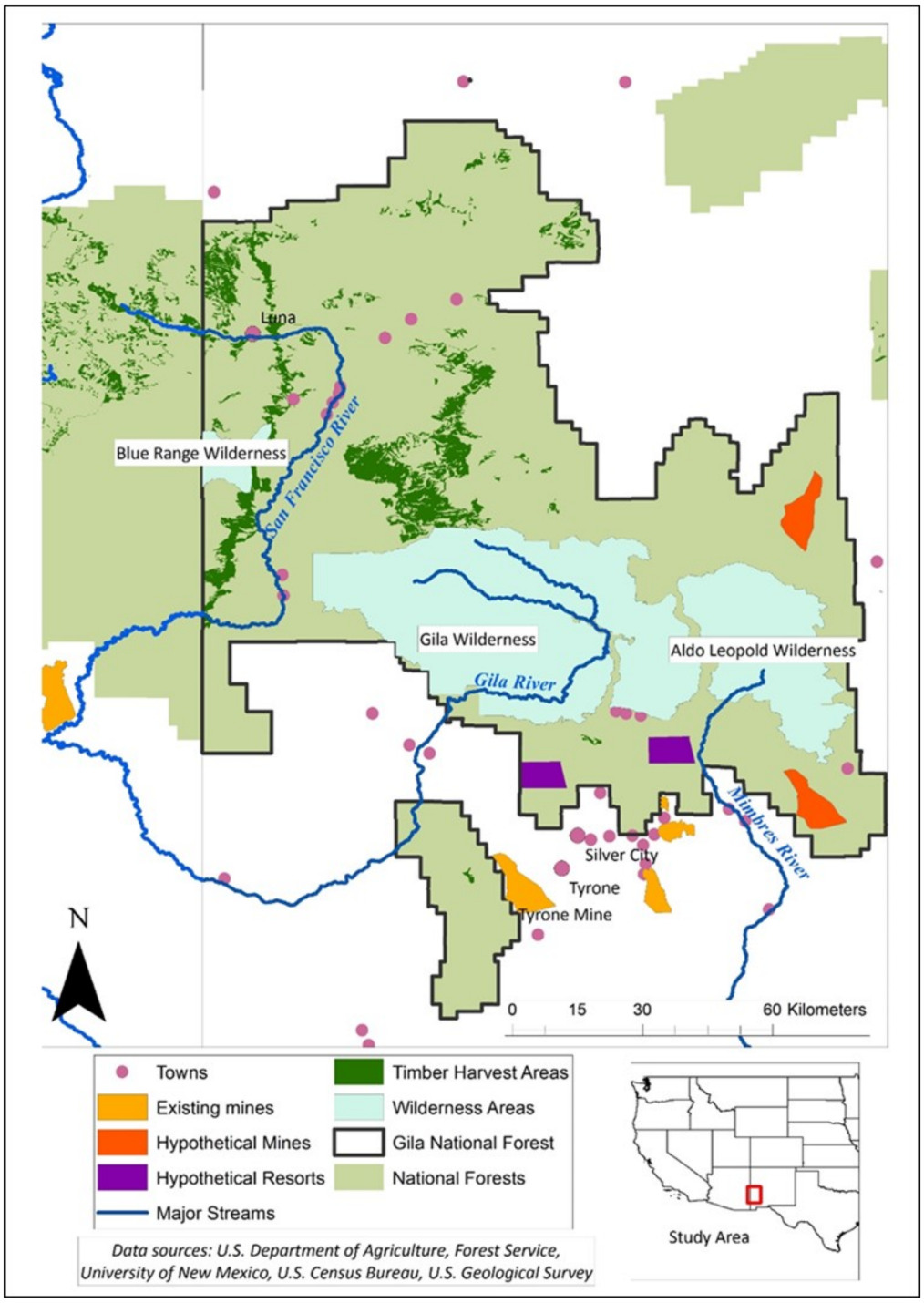

Figure 1. Map of Gila National Forest. Gila National Forest is located near several other protected areas, but is far from urban centers. Timber harvesting generally occurs at higher elevations. Grazing takes place on grasslands at lower elevations, including in wilderness areas.

3. Gila National Forest as a Social-Ecological System

3.1 Stakeholders

Gila National Forest serves a wide variety of stakeholders through various uses and activities. Recreational users provide substantial support to the local economy (USDA 2016). Hiking and backpacking are very popular within the forest; GNF, the Wilderness Areas, and GCDNM contain approximately 800 km of hiking trails. The Continental Divide Trail, which extends from Canada to Mexico through the Rocky Mountains, also runs ~88 km through GNF. Many of

the hiking trails are available for mountain biking, horse riding, and off-highway vehicle use. There are 25 campgrounds and four picnic areas within GNF. Other recreational stakeholders include hunters and fishers (Forest Service 2017).

Approximately 50,000 people live in the counties containing GNF (USDA 2016). In addition to year-round residents, the GNF area contains roughly 3,100 seasonal homes (USDA 2016). Both permanent and seasonal residents are concerned with fire management (Forest Service 2016) due to the encroachment of the wildland-urban interface (WUI) on the forest. Thirty-two per cent of homes in the GNF area are within the WUI (USDA 2016). The placement of homes and infrastructure near wildland areas, along with land management, timber harvest, and grazing practices, increases the risk and cost of property damage due to wildfires (Boucher and Moody 1998).

Water availability and quality are also top concerns of residents (USDA 2016). Much of this concern stems from grazing, as water is needed for livestock. Nearby residents also use water from the Gila River for irrigation via 30 acequias (USDA 2016), which are communally-owned and managed irrigation ditches with much historic, cultural, and economic value (Raheem 2014). Downstream, the Gila River Indian Community is granted an annual allocation of 806 million m^3 of water from the Gila River, which they use for irrigation of their agricultural lands in Central Arizona (Dejong 2014). The Gila River also supplies municipal drinking water for small towns downstream of the forest.

Other stakeholders include government and educational entities, including universities that use the forest for education and research. Ten Native American tribes have governmental partnerships with GNF. These tribes value the forest for hunting and gathering, education, and habitat for wildlife and native plants (USDA 2016). Various levels of government are involved in the administration of GNF, including county governments, which are responsible for providing supplemental law enforcement to the forest (Heild 2016).

3.2 Human-Environment Interactions in GNF

Though GNF is a protected land, it has not been insulated from the effects of human activities. Human-induced changes to the landscape have impacted GNF in a variety of ways. Overgrazing has caused extensive soil erosion in the forest (Chiaviello 2003), and has resulted in the conversion of some grasslands to woodlands (USDA, 2016). Along with introduction of exotics, these conditions have allowed non-native species such as saltcedar (*Tamarix spp.*) to invade the ecosystem and outcompete native taxa for resources (Whiteman 2006). Saltcedar is known for narrowing river channels, reducing streamflow, and providing less suitable habitat for nesting birds (Manners et al. 2014; Smith and Finch 2014).

Forestry and fire management practices have also altered the environment in GNF. Historically, the forest contained fewer trees and more grasslands than are currently present (Boucher and Moody 1998). Vegetation species turnover due to changes in fire regime has been significant (Forest Service 2016). Frequent, low-intensity fires provide a check on overgrowth by trees, but fire suppression causes fuel loads to build up, leading to less frequent, more intense fires which can devastate the ecosystem. Because of the remote location of GNF, fires are more difficult to suppress, which sometimes results in more frequent fires that are closer to the natural cycle of fire than may be found at other protected lands (Boucher and Moody 1998). However, this has not prevented occasional devastating wildfires in GNF, like the Luna fire in 2011. A flood following this fire caused further damage (Forest Service 2016). Changes to the vegetative structure and composition of the forest continue to occur following these disturbances (Forest Service 2016).

Fires, floods, overgrazing, exotic introductions, and other anthropogenic disturbances have led to the decline of several key species, including the Gila trout (*Oncorhynchus gilae*) and the Mexican spotted owl (*Strix occidentalis lucida*). Both of these species are protected under the Endangered Species Act, and many more species of concern (NatureServe ranked G3-G1) and critical habitat can be found in GNF (Lee et al. 2008; FWS 2016; Appendix A).

4. Ecosystem Services Valuation of Gila National Forest

The first step in valuating ES is to identify the services applicable to the given area (e.g., Mueller et al. 2016), which we did for GNF using the TEEB (2010) classification of provisioning, regulating, supporting, and cultural services (Table 1). We used global-scale values for most regulating and provisioning services because there have been few studies on the valuation of ES in arid and semi-arid forests relevant to our study area. For

Table 1. Ecosystem services of Gila National Forest (modelled after Mueller et al. 2016).

Category	Ecosystem Service	Study Example	Scale	Inclusion
Provisioning	Food	USDA, 2016	Regional	Yes
	Raw materials	Joshi, et al. 2017	Regional	Yes
	Water	de Groot, et al. 2012	Global	Yes
Regulating	Climate regulation	Costanza, et al. 1997	Global	Yes
	Nutrient cycling	de Groot, et al. 2012	Global	Yes
	Disturbance regulation	de Groot, et al. 2012	Global	Yes
	Erosion prevention	de Groot, et al. 2012	Global	Yes
	Pollination	de Groot, et al. 2012	Global	Yes
	Disease control	de Groot, et al. 2012	Global	Yes
Supporting	Habitat	Pearce, 2001	Regional	Yes
	Genetic diversity	Pearce, 2001	Global	Yes
Cultural	Recreation	Mueller, et al. 2016	Regional	Yes
	Tourism	Fay, et al. 2010	Regional	Yes
	Amenity and aesthetics	Pearce, 2001	Regional	Yes
	Science and education	-	-	No
	Spiritual values	-	-	No

all other ES, including supporting and cultural, we used regional-scale data (Table 2). All ecosystem service values were calculated for the entire protected area, based on area-normalized estimates (in US$/ha/y) for each land cover: 156,000 ha of grassland, 429,000 ha woodland, and 715,000 ha of temperate forest. Because our estimates are based on multiple studies, we also include ranges of values using the standard deviations from the studies cited in de Groot et al. (2012).

Using area-normalized values for provisioning services, we found the total value of water resources to be approximately $237 million (Table 3). We did not use water budgets to refine this estimate because surface water-groundwater interactions have not been appropriately quantified, particularly within the context of regional groundwater supply (Hawley et al. 2010). Although our study area is sparsely populated, the Gila River (and all its contributions) deliver irrigation and drinking water downstream, notably to central Arizona (Dejong 2014). Our estimate for food provisioning (via rangeland cattle) was $27,000 (Table 3). This value is lower than expected relative to global studies on ES (Costanza et al. 1997, 2014; de Groot et al. 2012). This estimate is derived from mean annual cattle sales (2012-2014) in the four counties that surround GNF (Catron, Grant, Hidalgo and Sierra; USDA 2016). Livestock grazing is the only form of agriculture in GNF (USDA 2016), and overgrazing has contributed ecological problems there (Smith and Finch 2014; USDA 2016). To expand this service could lead to the degradation of other services, including provisioning services, as overgrazing could lead to the reduction of available grazing land (USDA 2016). Raw materials were valued at $44 million, with timber stumpage prices as an indicator (e.g. Joshi et al. 2017). We used the range of miscellaneous hardwood prices for the Southwest region in 2016 (4th quarter; Penn State Extension 2017). These values were multiplied by the 10-year average timber harvest for GNF (USDA 2016).

Global averages were used to value all regulating

Table 2. Ecosystem service indicators and pricing methods (modelled after Mueller et al. 2014).

Ecosystem Service	Pricing	Indicator	Valuation details	Data Source	Applicable methods and data in literature
Food	Regional values	Cattle sales	Cattle sales for region 2012-2014	USDA, 2016	de Groot, et al. 2012
Raw materials	Market pricing	Volume of timber	4Q 2016 stumpage value of misc. hardwood timber	USDA, 2016	Joshi, et al. 2017
Water	Global values	Value based on biomes	Global values for temperate forest, grasslands, woodlands, and rivers	de Groot, et al. 2012	de Groot, et al. 2012
Climate regulation	Global values	Value based on biomes	Global values for temperate forest, grasslands, woodlands, and rivers	de Groot, et al. 2012	de Groot, et al. 2012
Nutrient cycling	Global values	Value based on biomes	Global values for temperate forest, grasslands, woodlands, and rivers	de Groot, et al. 2012	de Groot, et al. 2012
Disturbance regulation	Global values	Value based on biomes	Global values for tropical forests	de Groot, et al. 2012	de Groot, et al. 2012
Erosion prevention	Global values	Value based on biomes	Global values for temperate forest, grasslands, and woodlands	de Groot, et al. 2012	de Groot, et al. 2012
Pollination	Global values	Value based on biomes	Global values for temperate forest, grasslands, woodlands, and rivers	de Groot, et al. 2012	de Groot, et al. 2012
Disease control	Global values	Value based on biomes	Global values for temperate forest, grasslands, woodlands, and rivers	de Groot, et al. 2012	de Groot, et al. 2012
Habitat	Willingness to pay (WTP)	WTP for protection of critical habitat	Habitat of Mexican spotted owl	Loomis and Ekstrand, 1998	Pearce, 2001
Genetic diversity	Global values	Value based on biomes	Global values for temperate forest, grasslands, woodlands, and rivers	Pearce, et al. 2001	
Recreation	Income/ production	Average expenditures	New Mexico residents' recreation-related expenses in 1996	NMSF, 2001	Mueller, et al. 2016
Tourism	Income	Percentage of income from recreation	Percentage of local income associated with tourism, hospitality and recreation	USDA, 2016	Mueller, et al. 2016
Amenity and aesthetics	Property-tax revenue	County mil rate	Mil rates for vacation homes	USDA, 2016	Mueller, et al. 2016

Table 3. Values of ecosystem services for Gila National Forest (GNF). Values are in 2016 USD, calculated from area-normalized estimates (US$/ha/y). Amounts are in millions.

Ecosystem Service	**Indicator**	US$ in millions **Low Estimate**	US$ in millions **High Estimate**
Food	Cattle sales	0.026	0.026
Raw materials	Volume of timber	19	69
Water	Global values	230	243
Climate regulation	Global values	180	193
Nutrient cycling	Global values	105	117
Disturbance regulation	Global values	83	108
Erosion prevention	Global values	14	22
Pollination	Global values	5	18
Disease control	Global values	275	288
Habitat	WTP for spotted owl habitat	19	24
Genetic diversity	Global values	1,170	1,180
Recreation	Income/Production	48	70
Tourism	Income	52	178
Amenity and aesthetics	Property taxes	8	9
Total economic value		2,208	2,519

services. We used the estimates from de Groot, et al. (2012) with ranges based on standard deviations. Because values for disturbance regulation were not available for temperate forest, woodlands or grasslands, we used global values for tropical forests. However, due to differences in vegetation and soil dynamics between temperate and tropical climates, this value is most likely low.

Habitat value was based on a willingness-to-pay (WTP) survey by Loomis and Ekstrand (1998) which asked participants to value Mexican spotted owl (Strix occidentalis lucida) habitat. The Mexican spotted owl is a federally-listed threatened species (Appendix A) which has critical habitat in GNF. We applied the WTP value ($40.49 per person; Loomis and Ekstrand 1998) to the number of visitors in GNF each year. The total habitat value is roughly $21 million.

Outdoor recreational spending in New Mexico ranged from $929 – 1,352 per person, per year (NMSF 2001), and the Forest Service reported 514,000 annual visitors to GNF in 2011 (the most recent figure available; USDA 2016). Not all of this value would come from GNF, however. Some of this spending could be used at additional federal lands as well. GNF comprises approximately 10% of the federal land in New Mexico. We calculated the recreational value at 10% of the total recreational spending of 514,000 visitors. This amounts to $59 million for recreation services annually. Local income from hospitality, entertainment, and recreation represented tourism values, which total $115 million. These industries make up 3-10% of the local economy for the four-county area that contains GNF (Grant, Catron, Sierra and Hidalgo Counties; USDA 2016). We estimated amenity and aesthetics at $8.5 million. The indicator for this variable is the approximate amount of property tax the counties receive for vacation homes. This figure is based on the average home price in New Mexico (range based on standard deviation; Flanagan and Wilson 2013) multiplied by the number of intermittently-occupied homes in the four counties that contain portions of GNF. The total price for vacation homes is multiplied by the average residential mil rate (county property tax) for Grant County, the only county in the GNF vicinity which had mil rates available. Although GNF contains several archaeological sites and other culturally

important resources (Bird-Gauvin 2002; Russell 1992), we did not assess science, education, or spiritual values because there was not available data.

Total value for of all ES was $2,364 million per year, with a range of $2,208 – 2,519 million (Table 3). These values do not include disturbance regulation and erosion prevention because that variable was indicated by a value relative to the magnitude of a disturbance.

5. Trade-offs and Damage Costs from Potential Development

In addition to the total values of ES, trade-offs and damage costs must be considered because both variables affect the total value. ES often are related to and depend upon one another, but they can also be in conflict with one another (Kline and Mazzotta 2012). This idea is critical to the management of ecosystems because prioritizing management practices to maximize one ecosystem service can cause the degradation of other services. When two or more ES are competing, each service can increase in value up to a certain limit, where a threshold is crossed and one service only increases at the expense of the others. Kline and Mazzotta (2012, p. 15) refer to this threshold as the 'production possibility frontier'.

It is important to acknowledge potential trade-offs and production possibility frontiers in any ecosystem service valuation analysis, as these factors guide management decisions (Kline and Mazzotta 2012). For example, timber production in GNF is valuable, but that value comes at the expense of other ES. If a large portion of the available timber were harvested, then habitat, cultural services, and regulating services would all decline. Alternatively, if the Forest Service were to identify habitat as a priority above all other services, that could result in losses in recreation (due to trail closures), raw materials production, and food production (via limitations on grazing). Recreation could also cause the decline of ES if not managed appropriately, resulting in degradation of habitat, disturbance regulation, erosion prevention, and raw materials.

In addition to trade-offs, damage costs should also be considered. Damage costs for this analysis were estimated based on the hypothetical loss of federal protections on GNF. The transfer of federal lands to states or private interests has been a widely debated issue in U.S. politics, and continues to be a concern for many stakeholders. Recently, a bill was introduced by a congressman that would have transferred approximately 1.2 million ha of federal land, nearly the same land area as GNF, to states, making it easier to sell these lands to private entities (Eilpern 2017b). The loss of federal protections on these lands could result in ecological damage that would cause declines in some ES.

Ecological damage can be a consequence of poor management practices, and the privatization of GNF could place the land in the hands of owners who do not prioritize land stewardship. Grazing often has a negative impact on ecosystems, often causing the degradation of other ES, such as water quality and biodiversity (Havstad et al. 2007). Because of damage already caused by overgrazing in GNF (Smith and Finch 2014; USDA 2016), it is possible that the value of grazing in this area may be less than the damages associated with it. Grazing-related erosion problems (Chiaviello 2003; Smith and Finch 2014; Whiteman 2006) and vegetation changes have already been reported in GNF (USDA 2016), and deregulation would likely increase these impacts considerably. Intensified erosion from overgrazing would result in changes in riparian tree species, which would affect bird habitat (Smith and Finch 2014), and would further endanger the Gila trout (Brown et al. 2001). Since bird watching and fishing are included in recreation value and tourism, these values would likely decline if overgrazing were permitted.

If the non-wilderness areas of GNF were completely privatized, changes to recreation and tourism values could occur. Depending on how the land is used after privatization, recreation may either increase or decrease. For example, if parts of the forest were converted to a large resort development with a golf course, recreation spending could increase. A 2009 survey by Golf Magazine found that the average golfer spends about $3,106 per year on golf (Barrett 2011). This particular land use change would result in far fewer users who are spending more money. Using an estimated 800 unique golfers per year, we determined that golf courses would increase the recreation value of GNF by $2.4 million. Amenity and aesthetic values would increase if a resort were added, because more homes would be built on the former forest lands, but again for only a select group of people.

To value damages to these services, we used a nearby golf resort development, Turtleback Mountain Resort in Sierra County, New Mexico as a proxy. This 364-ha resort contains 200 homes, along with Sierra del Rio Championship Golf Course (Scott 2013). Since this is a luxury resort, home values would most likely be higher than average; we assumed a mean value of $200,000 per home for this analysis. This adds property taxes to the area, resulting in a higher value for amenity

and aesthetics damages.

Since GNF covers such a large area, we can assume that more than one golf resort could potentially be built. It is unlikely that the wilderness areas would be developed for this purpose because they are so important to recreation and conservation, but there could potentially be at least two such resorts in the southern portions of GNF, close to Silver City. Two resorts of similar size to Turtleback Mountain would reduce the land available for other types of recreation by 0.6%. The values of some services would not likely change significantly under this scenario. For example, climate regulation values might be similar under the golf resort scenario because vegetation cover would remain high for the most part.

Additional damages could result if GNF became open to mining. Several copper mines operate in the immediate vicinity of GNF, including Tyrone Mine which is immediately adjacent to GNF. The Tyrone Mine contains approximately 30,600 tons of copper recoverable over a 25-year period between 2016 and 2041 (1,224 tons annually; Freeport-McMoRan 2017). As of December 2016, copper prices were at $5660.35/ton (Index Mundi 2018). The placement of two mines similar to the Tyrone Mine would add approximately $13.9 million to raw materials services, but would also cause reductions in other services. Since vegetation would have to be completely removed for a copper mine, some ES would be completely eliminated. The footprint of the mine is approximately 5400 ha, which is 0.4% of the total area of GNF. In order to estimate additional damages from the placement of two copper mines in GNF, we added 0.8% to the reduction values for most other services. With two resorts and two mines, the total damages were calculated for 1.4% of GNF.

Fire damages were used to value damage costs for both disturbance regulation and erosion prevention. Fire is a huge concern for the stakeholders in GNF (e.g., thousands of acres are burning as we write this article in June 2017), and the effects could be magnified with development. If parts of GNF were to become privatized, it could lose some of the comprehensive fire management that exists today. In addition, development of a portion of the forest into a residential neighborhood would likely result in more frequent and more damaging wildfires (Clark et al. 2016; Chas-Amil et al. 2015). We used a range of values related to estimated costs of fires in Arizona, Colorado, and New Mexico between 2000 and 2003 as reported by Western Forestry Leadership Coalition (WFLC 2009). Suppression costs for these fires were used to value disturbance regulation damages; rehabilitation costs were used as a proxy for erosion prevention damages. Costs of replacing electric infrastructure were also calculated as part of disturbance regulation. Electric transmission lines are generally priced per mile in this area (Black and Veatch Corporation 2014); we used the size of a recent fire in GNF to determine total price.

If large areas of GNF were bought by private entities, changes in management practices could lead to increased pollution of river waters. Both water availability and water quality are pressing concerns in GNF (USDA 2016). Any development would likely impact both of these services. There are many other ES provided by the ephemeral and intermittent streams in GNF (Koundouri et al. 2017) that we did not take into account in our analysis. Since human population in the forest is low, the effects on native fish species would be much more of a concern than the effects of water quality changes on humans. For this reason, we chose to use the numbers from Mueller et al. (2016) to determine the damage cost of water degradation. Mueller et al. (2016) modelled changes in ES due to eutrophication of a lake in New Zealand, and found that biodiversity of native fish species declined 5-15%.

Habitat damage costs were calculated using average declines in native fish species following a pair of consecutive large wildfires near the Gila River in 2011 and 2012. Whitney et al. (2015) measured biomass of fish and aquatic insects before the fires and again after each fire. They found a 74% average decline of native fish species. Declines for aquatic insects were similar, but we used fish for this analysis because GNF has several federally-listed fish species and only one proposed insect species (Appendix A). Genetic diversity losses would reduce the resilience of GNF to disturbances such as fires and pest infestations. Pearce (2001) estimated that option value for temperate forests is approximately $95/ha. We used this value because genetic diversity is an important part of option value (Bartkowski 2017).

Overall, total damage costs from privatization of GNF ranged from $80 – 271 million (Table 4). This value takes into account damages (raw materials, water, disturbance regulation, habitat, genetic diversity, recreation) and enhancements (raw materials, amenity and aesthetics).

6. Discussion and Conclusions

According to our analyses, the ES of Gila National Forest (GNF) are annually worth $2.364

Table 4. Damage costs of ecosystem services from potential development of Gila National Forest (GNF). Values are in 2016 US$, calculated from area-normalized estimates (US$/ha/y). Amounts are in millions.

Ecosystem Service	**Change in value**	(US$ in millions) **Low Estimate**	(US$ in millions) **High Estimate**
Food	-1.4%	negligible	negligible
Raw materials	Added value of copper	+13.9	+13.9
	Loss of timber (-0.6%)	-0.1	-0.4
Water	-10%	-23	- 24
Climate regulation	-0.8%	-1.4	-1.5
Nutrient cycling	-1.4%	-1.5	-1.6
Disturbance regulation	Fire suppression	-42	-53
	Infrastructure replacement	-10	-157
Erosion prevention	Post-fire rehabilitation	-15	-45
Pollination	-0.8%	-0.1	-0.1
Disease control	-1.4%	-3.9	-4
Habitat	-1.4%	-0.3	-0.3
Genetic diversity	Loss of option value per hectare	-1.7	-1.7
Recreation	Added golf recreation	+2.4	+2.4
	Reduced other recreation (-1.4%)	-0.7	-1
Tourism	-0.8%	-0.4	-1.4
Amenity and aesthetics	+17%	+1.4	+1.4
2016 total economic value		2,208	2,519
Development value changes		-82	-273
Total value with proposed development		2,126	2,246

billion. While this estimate involves several assumptions and a great deal of uncertainty, we use it to represent the collective value of the many natural resources, ecological functions, and cultural amenities that have been documented for this protected area. Our total economic value for GNF is comparable to other systems studies (Costanza et al. 2014; de Groot et al. 2012). With that said, our use of global values to represent local values for ES has some caveats. Economic values of services can vary significantly depending on local variables. For example, Kreye et al. (2014) found considerable differences in WTP for water quality based on region within the USA. Global values are based on local studies on ES valuation (de Groot et al. 2012), so applying those values to another place is not ideal.

There are inherent issues with reducing an ecosystem or its functions to a monetary value (Wilson, 2016). A particular problem arises with the valuation of ES that can be beneficial in more than one way. Valuation of biodiversity exemplifies this idea (Laurila-Pant et al. 2015; Leinhoop et al. 2015; TEEB 2010). A biodiverse ecosystem boosts the value of all ES, but much of its value lies in potential future use (Bartkowski 2017). Future values cannot be fully accounted for because they are unknown (Wilson 2016; Bartkowski 2017). Services which may become more valuable with time would hold more economic value now because there would be more incentive to preserve them. For this reason, this study does not consider future values, but it should be noted that some services are likely undervalued for this reason. Additionally, the use of aggregate values of many ES, as we have done here, increases the risk of double-counting some services (Turner et al. 2010). Some services enhance the value of other services, therefore including both services in the total value results in counting a portion of the value twice. Using aggregate values is common in ecosystem service valuations (i.e., Costanza et al. 1997; 2014), but the risk of double-counting is a caveat that deserves recognition. While we acknowledge the uncertainty in our ecosystem service values, our emphasis is the relative changes in value with policy changes and

management decisions of this federally protected land.

Some of the methods we used to determine economic values and damage costs require further explanation. The methods used to calculate tourism values isolate local income related to tourism, and separate other tourism value that may be counted in recreation values. This excludes tourism value that is not concentrated at the immediate location of GNF. For example, it leaves out airfare and hospitality income in other areas. If these values could be included, the value for tourism may be much higher, particularly if a significant number of visitors travel great distances to GNF. Values for amenities and aesthetics were derived from county property taxes on vacation homes. Typically, more analytical methods, such as hedonic pricing, are used to capture ecosystem service values from property values. We chose to use county mil rates instead for two reasons. First, previous studies (e.g., Ham et al. 2012) found that proximity to a National Forest, especially a quiet section of the forest (such as a wilderness area) increases property values. Second, county mil rates are much more accessible than real estate records, and we wanted to keep our methods as simple as possible in order to demonstrate that valuation of ES could be done with readily available data.

For some other services, values were difficult to capture. Cultural services in this case study are certainly undervalued. Several parts of the forest are of particular importance to Native American tribes, so spiritual values are probably quite high. We used cattle sales to represent food values for this analysis, but rangelands may have much more value as cultural services than as provisioning services. Havstad et al. (2007) found that cultural and regulating services are often much more important in rangelands because ranching is often done as a hobby, rather than as a profession.

Science and education values may also be significant, but were not valued in this analysis because the data were missing. Specific numbers for student visitation in GNF were not available, but GNF and adjacent Apache National Forest paid over $3 million per year (2013-2014) in Secure Rural Schools Act (SRS) payments to Grant, Catron, Sierra and Hidalgo Counties (USDA 2016). These payments support schools in counties near Forest Service or Bureau of Land Management lands. If GNF were sold to private entities, the schools in these counties would no longer receive most of this support (Catron County receives some SRS payments from Apache National Forest; presumably these payments would continue as long as Apache NF remained protected; USDA 2016). However, an increased tax base from development may mitigate this lost funding.

Development of GNF would certainly have a negative impact on water quality for downstream stakeholders. The addition of impervious surfaces would increase storm water runoff, intensifying erosion and introducing additional pollutants into the waterways. Since sedimentation following storm events is already a problem in some waterways in GNF (Forest Service 2016), mitigation via infrastructure would be necessary in the event of development. Land use changes associated with development would impact water quality as well. The short grasses found on golf courses and manicured lawns do little to slow runoff, and these types of land uses would introduce fertilizers to the streams. It is important to reiterate the consequences of development on the frequency and intensity of disturbance. The most significant disturbances affecting GNF are fires and post-fire floods, which cause widespread changes in vegetation (Forest Service 2016) and aquatic habitat (Brown et al. 2001). Land-use and land management changes could cause these types of disturbances to be more destructive in relation to property and ecosystem damage. Based on our calculations (Table 4), damage costs resulting from the privatization of just a small portion of GNF (1.4%) totaled $82– 273 million per year. This would lower the total annual value of ES to $2,126 – 2,246 million. This value does not take into account the effect on nearby protected areas which depend on their connectivity to GNF.

The close proximity of GNF to other protected lands is an important factor in the valuation of ES because it allows for some connectivity between patches of protected areas. Connectivity raises the insurance value against future declines in ES and ensures resilience to disturbances (Bartkowski 2017). Insurance value raises the overall value in theory, but determining an exact monetary value of insurance is difficult. Gila National Forest lies on the New Mexico-Arizona border, and is close in proximity to other protected lands (Figure 1). Apache National Forest borders GNF to the north, and is at least partly managed by GNF. To the west of GNF, just across the Arizona border, are portions of Apache and Sitgreaves National Forests, which are bordered on their west by the Fort Apache and San Carlos Native American Reservations. Several additional tribal lands are located to the north of GNF, including the Navajo and Hopi Reservations to the northwest and the Zuni Reservation and the Ojo and Acoma Pueblos to the Northeast. Patches of Cibola National Forest lie to the east of GNF, along with some private conservation lands and Bureau of Land

Management (GAP status 3) federal lands. Thus, ES lost at GNF could affect the values of these neighboring lands, which was beyond the scope of our study.

Efforts to enhance ES are currently underway in GNF. Conservancy organizations, such as the New Mexico Land Conservancy work with land owners to increase the amount of protected private land near GNF via conservation easements (NMLC 2010). Restoration projects which aim to mitigate the effects of natural and manmade disturbances are being administered by NGOs as well as the Forest Service (Forest Service 2016; Wild Earth Guardians 2017). However, development pressures and resource extraction are encroaching on GNF (USDA 2017), and there will likely be land sales/ swaps to address management goals and costs (USDA 2016; USDA 2017). GNF has not been directly targeted for transfer to state or local entities, but given it contains mineral resources, land swaps or sales could be used to fund other resource management priorities in the forest. The current Forest Plan, approved in 1986, mentions adjustments of land ownership in order to adequately address resource management in the forest and growth in the surrounding communities (USDA 1986; USDA 2017). In closing, this study emphasizes the importance (and value) of conducting ES inventories, trade-off analyses, and damage cost assessments. The ecosystem services provided by Gila National Forest are crucial to the economy at all scales (from local to global), and the benefits provided by those services are available as long as the land remains protected.

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Appendix A: Federally-listed species and critical habitat in Gila National Forest
Federally listed species under the Endangered Species Act. These species are all federally-protected species which reside either permanently or seasonally within GNF (FWS, 2016).

* indicates that a critical habitat has been proposed within GNF boundaries.

Common name	Scientific name	Species type	Status	Critical habitat in GNF
Southwestern willow flycatcher	*Empidonax trailii extimus*	Bird	Endangered	Yes
Least tern	*Sterna antillarum*	Bird	Endangered	No
Gila chub	*Gila intermedia*	Fish	Endangered	Yes
Loach minnow	*Tiaroga cobitis*	Fish	Endangered	Yes
Spikedace	*Meda fulgida*	Fish	Endangered	Yes
Gila topminnow	*Poeciliopsis occidentalis*	Fish	Endangered	No
Mexican wolf	*Canus lupus* ssp. *baileyi*	Mammal	Endangered	No
Mexican long-nosed bat	*Leptonycteris nivalis*	Mammal	Endangered	No
Chiricahua leopard frog	*Lithobates chiricahuensis*	Amphibian	Threatened	Yes
Mexican spotted owl	*Strix occidentalis lucida*	Bird	Threatened	Yes
Yellow-billed cuckoo	*Coccyzus americanus*	Bird	Threatened	Yes
Gila trout	*Oncorhynchus gilae*	Fish	Threatened	No
Chihuahua chub	*Gila nigrescens*	Fish	Threatened	No
Beautiful shiner	*Cyprinella formosa*	Fish	Threatened	No
Northern Mexican garter snake	*Thamnophis eques megal-ops*	Reptile	Threatened	Yes
Narrow-headed garter snake	*Thamnophis rufipunctatus*	Reptile	Threatened	Yes
Zuni fleabane	*Erigeron rhizomatus*	Plant	Threatened	No
Gila mayfly	*Lachlania dencyanna*	Insect	Under review	No*
Roundtail chub	*Gila robusta*	Fish	Proposed	No
Headwater chub	*Gila nigra*	Fish	Proposed	No
Bald eagle	*Haliaeetus leucocephalus*	Bird	Delisted	No