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Source: Air, Soil and Water Research, 13(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1178622120913318

Air, Soil and Water Research
Volume 13: 1–16
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DOI: 10.1177/1178622120913318
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Mapping Perceived Social Values to Support a Respondent-Defined Restoration Economy: Case Study in Southeastern Arizona, USA

Roy E Petrakis[1], Laura M Norman[1], Oliver Lysaght[2,3], Benson C Sherrouse[4], Darius Semmens[4], Kenneth J Bagstad[4] and Richard Pritzlaff[2,5]

[1]Western Geographic Science Center, US Geological Survey, Tucson, AZ, USA. [2]Borderlands Restoration Network, Patagonia, AZ, USA. [3]The London School of Economics and Political Science (LSE), University of London, London, UK. [4]Geosciences and Environmental Change Science Center, US Geological Survey, Denver, CO, USA. [5]The Biophilia Foundation, Chester, MD, USA.

ABSTRACT: Investment in conservation and ecological restoration depends on various socioeconomic factors and the social license for these activities. Our study demonstrates a method for targeting management of ecosystem services based on social values, identified by respondents through a collection of social survey data. We applied the Social Values for Ecosystem Services (SolVES) geographic information systems (GIS)-based tool in the Sonoita Creek watershed, Arizona, to map social values across the watershed. The survey focused on how respondents engage with the landscape, including through their ranking of 12 social values (eg, recreational, economic, or aesthetic value) and their placement of points on a map to identify their associations with the landscape. Additional information was elicited regarding how respondents engaged with water and various land uses, as well as their familiarity with restoration terminology. Results show how respondents perceive benefits from the natural environment. Specifically, maps of social values on the landscape show high social value along streamlines. Life-sustaining services, biological diversity, and aesthetics were the respondents' highest rated social values. Land surrounding National Forest and private lands had lower values than conservation-based and state-owned areas, which we associate with landscape features. Results can inform watershed management by allowing managers to consider social values when prioritizing restoration or conservation investments.

KEYWORDS: SolVES, ecosystem services, social survey, PPGIS, restoration economy

RECEIVED: November 18, 2019. **ACCEPTED:** February 25, 2020.

TYPE: Original Research

FUNDING: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Funding for the project was provided with support from the Land Change Science (LCS) Program, under the Land Resources Mission Area of the U.S. Geological Survey (USGS).

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Roy E Petrakis, Western Geographic Science Center, US Geological Survey, 520 N. Park Avenue, Tucson, AZ 85719, USA.
Email: rpetrakis@usgs.gov

Background

Ecosystem services (ES) frameworks have been developed to influence natural resource management with the overarching goal to maintain or enhance valued elements of nature.[1,2] ES are the various benefits provided by nature to people,[3] including those associated with healthy, biologically diverse natural habitats such as forests, urban green spaces, wetlands (marshes and swamps), grasslands, and rivers. Possible benefits could include water purification and availability, increased biodiversity, or areas for recreation or ceremony. ES are also highly dependent on the intent and effects of land-management activities.[4] Developing an active restoration economy can support land-management objectives, including the provision of ES. For the purpose of this research, we developed a hybrid definition built on multiple sources that defines a restoration economy as the process of improving ecosystem health by returning damaged or degraded ecosystems to their original state through activities or investments in the landscape, resulting in an economic return,[5-7] such as recovered flows of ES.

Both the private and public sectors can promote an active restoration economy.[8] Conservation by the private sector can protect land, and the ES it supports, from land-use changes—such as development—by using trusts, easements, and other incentives, while allowing the land to remain economically profitable to the owner. An example of conservation through the private sector includes The Nature Conservancy's (TNC)[9] various conservation-based land-management activities. Public, state, and federal agencies can partner with and fund organizations that undertake restoration efforts, protect land for conservation covenants and habitat restoration, and are responsible for developing regulations that impact current and future restoration efforts.[10-12]

Different methods can inform land managers of where either restoration should take place or where high ecological value is located on the landscape, including the identification of areas where large numbers of species are supported, called "biodiversity hotspots."[13] However, to allocate funding efficiently, successful conservation investment should address socioeconomic factors as well as ecological ones.[13,14] Social values portray how communities perceive the natural environment based on individual experiences. Methods addressing socioeconomic factors have been used for site selection in support of land conservation[15] and developing frameworks for ES policies for the flow of binational effluent in the Santa Cruz Watershed, United States/Mexico border region.[16,17] Nonetheless, effective buy-in for conservation planning depends on stakeholders' willingness and capacity to participate and the expression of human values.[18,19]

Spatial modeling and mapping techniques can incorporate human values to inform land managers of where areas of ecological or social value exist on the landscape. Public participation geographic information systems (PPGIS) quantify location-based value using landscape properties, public survey data, and geographic information systems (GIS).[20] Many applications of PPGIS exist,[21] including for social-ecological hotspot mapping[22-24] and for mapping social values for ES.[25,26]

The Social Values for Ecosystem Services (SolVES) GIS application is a PPGIS-based tool that maps perceived social value, defined in Sherrouse et al[27] as the values perceived by the stakeholders, based on how and where respondents both experience and value the landscape they engage with.[27] The SolVES model links social values with physical properties, providing numerous outputs outlining these relationships that may be informative for natural resource managers.[27] SolVES has been used in many previous applications, including for conservation planning within watersheds,[28,29] to identify landscape and seascapes valued by different respondent subgroups in coastal areas,[30,31] to map social-ecological hotspots in combination with biophysical ES models in the Rocky Mountains of Colorado and Wyoming,[23,32] and to explore the transfer of values between sites based on physical and social characteristics.[33,34]

Various types of social surveys can be employed to determine people's preferences and incorporate socioeconomic factors in PPGIS analyses. Economic surveys often ask about respondents' willingness-to-pay (WTP) for a non-market (ie, environmental) product or service that is not typically bought and sold in conventional markets. Several applications using economic surveys have been developed in southeastern Arizona and across the Southwest U.S. Examples include using survey data to obtain WTP estimates for effluent use to maintain the riparian corridor of the Santa Cruz River from visitors to Federal and State Parks,[35] to link high value associated with riparian forests and water preferences along regional urban centers,[36,37] to determine water quality, quality of life, and/or perceptions of problems related to climate and land-use change in Nogales, Sonora, Mexico,[38,39] and to obtain WTP values for restoration and preservation alternatives for the Upper San Pedro River and restoration estimates for the Middle Rio Grande ecosystems.[40] Results suggest that choice experiment valuation methods, which allow respondents to select an alternative from a list, may more accurately elicit preferences for environmental goods by allowing respondents to compare tradeoffs between the results of plausible management alternatives.[41] The social survey we used solicits economic information from respondents through an assessment of their willingness-to-donate (WTD) to a community water fund as well as a question about their general income.

The goal of this research was to quantify community social values in a watershed, which could be compared to biophysical or economic values that are more traditionally used as basis for decision-making and the management of ES. A secondary objective was to inform the development of a respondent-based restoration economy by identifying locations for future conservation investments. Our methods were to (1) use the SolVES tool to map social value on the landscape by incorporating social survey data and environmental variables and (2) stratify the results by land ownership/management. We hypothesized that locations that were commonly visited or are well-known to the survey respondents, such as biodiversity hotspots, locations for tourism, and recreational areas, would have increased social value, and that ownership and environmental properties would influence spatial patterns of social value.

Methods

Sonoita Creek watershed

The Sonoita Creek watershed (area = 672 km^2), a fifth-level watershed of the U.S. Forest Service in southeast Arizona, United States (U.S.), surrounds the town of Patagonia (pop. 913[42]). High-elevation mountains drain into Sonoita Creek, a tributary of the Santa Cruz River (Figure 1). Pacific storms provide occasional snow during the winter months while monsoonal thunderstorms provide rain during the summer months.[43,44] The watershed is situated in the Madrean Archipelago Level III Ecoregion of the southwestern U.S. and northwestern Mexico.[45]

Several important wildlife corridors exist in this region, and their maintenance is important for wildlife movement across barriers, both physical (eg, roads, fences, structures) and non-physical (eg, ownership/management)[46] (Figure 1). The Arizona Scenic Trail runs north to south through Patagonia, then turns east from Patagonia[47] (Figure 1). In addition, Patagonia Lake—a man-made reservoir damming Sonoita Creek—is popular for boating, camping, and fishing. These examples highlight potential values for respondents of the social survey that are present within the watershed, such as numerous recreational opportunities and biodiversity.

Various entities own and manage land within the watershed (Figure 1). The Coronado National Forest, the only federal entity, owns the largest portion of the land (401 km^2 or 60%), which includes a portion of a wilderness area surrounding Mt. Wrightson. There is also a large allotment of private parcels, particularly in the lowlands along upper Sonoita Creek. State-owned lands include (1) the Arizona State Parks & Trails (Patagonia Lake State Park [PLSP] and the Sonoita Creek State Natural Area) – managed for conservation of state lands, (2) State Trust Land – managed to generate revenue to support education through sales, surface leases, and permitted recreation,[48] and (3) Arizona Game and Fish lands – managed for conservation and recreation[49] (Figure 1).

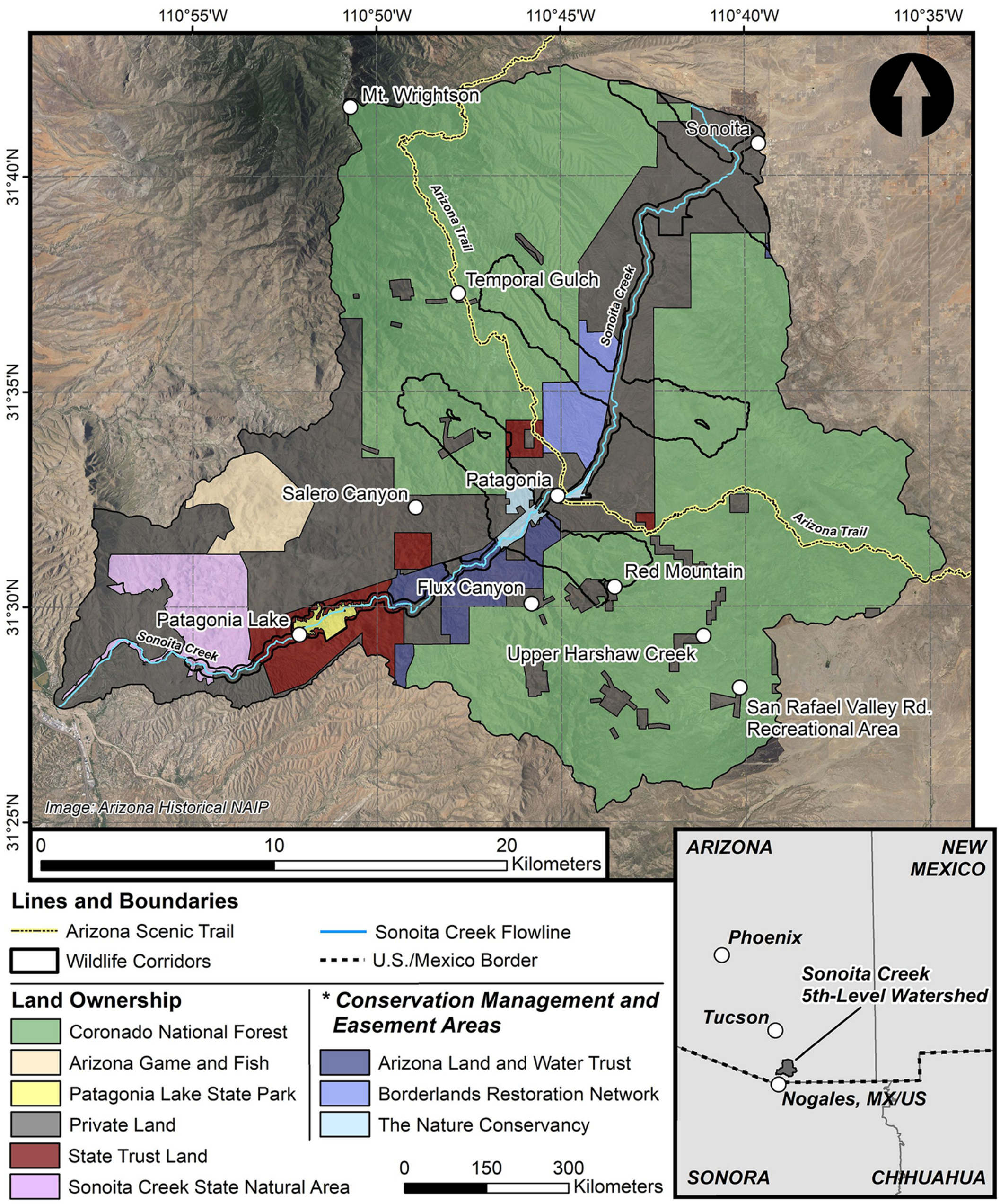

Figure 1. Ownership and land management entities for the study area—Sonoita Creek 5th-level watershed.

In addition, three conservation-based organizations own or manage land, including (1) the Borderlands Restoration Network (BRN), which focuses on developing a restoration-based economy,[50,51] (2) TNC,[52] a non-profit organization that integrates science with conservation, and (3) the Arizona Land and Water Trust (ALWT) that works with private land owners interested in conservation and preservation on Arizona's landscape and habitats[53] (Figure 1).

Public values surveys

This article describes the results of a survey that was administered by BRN in May 2017. The survey includes six components and documents the respondents' (1) economic and physical relationship to water, (2) attitudes for different land uses and participation in outdoor activities, (3) familiarity with natural environment terminology, (4) preferences for natural resource management, (5) social values related to their relationship to the environment, including specific value locations, and (6) personal information.[54,55] Each portion of the survey is designed to elicit responses about different ways in which the respondent may interact with the Sonoita Creek watershed. The survey responses were anonymous, with insights meant to guide local watershed management and strengthen restoration efforts; questions about social values and their locations were used as inputs for SolVES.

A total of 665 surveys were mailed to all P.O. boxes at the Patagonia postal office, covering both residential and

Table 1. The 12 social values considered in this study and their descriptions as provided in the survey instrument.

SOCIAL VALUE	DESCRIPTION
Aesthetic	. . . I enjoy the **aesthetics**—scenery, sights, sounds, smells, etc.—within it
Biological Diversity	. . . it is home to such **biological diversity**
Cultural	. . . it is a place of **cultural value** allowing me to pass down the knowledge, traditions, wisdom and way of life of myself and my ancestors
Economic	. . . it is a place of **economic value** where I can earn a living
Future Generations	. . . I want **future generations** to be able to know, see and experience the watershed
Historical	. . . it has **historic value**, with important places and things of natural and human history
Intrinsic	. . . it has **intrinsic value**, irrespective of any instrumental value
Learning	. . . because we can **learn** a great deal within it
Life Sustaining	. . . because it has **life sustaining value** through protecting and renewing clean air, soil, water etc.
Recreational	. . . because it provides a place for my favorite outdoor **recreation** activities
Spiritual	. . . because it has **spiritual** value to me in the form of sacred, religious, or spiritual or because I feel reverence and respect for nature there
Therapeutic	. . . because it has **therapeutic** value, making me feel better physically and/or mentally

non-residential properties. In addition, as many as 10 surveys were distributed at local events, including Patagonia's Water History event (March 18, 2017). The intent of this distribution approach was to include all members of the watershed, including those outside of the restoration-oriented community. No incentives were given to complete the survey, thus potentially resulting in self-selection and participation bias by the respondents.

We considered 12 social-value types in the survey, which have been used previously within other SolVES or social value elicitation applications[27,56] and were derived from a forest-values typology developed by Rolston and Coufal[57] (Table 1). Each respondent was asked to assign points for whichever of the 12 social values they felt were important to them and draw the location(s) where their assigned values occur on a paper map of the watershed. Each respondent could allocate 100 points across the 12 social values and could mark multiple locations on the map to represent areas where they hold a particular social value.

Points represent how much the respondents value each social value comparatively. The map that was provided to the respondents was scaled to roughly 1:175,000 and displayed reference information including boundaries of the National Forest, major roads, and mountain peaks. Respondents either drew a point, a circle, or an underline; then listed the values assigned to that location. If a circle or underline was drawn by the respondents, we placed a point that we interpreted to be the central point of the location.

Survey data review

We visualized survey outputs related to respondents' social and economic engagement with the watershed using the ggplot2 package in R Studio. Variables included the respondent's familiarity with the term restoration economy (not defined in the social survey), their WTD to a community water fund, opinions about various land uses, and level of concern regarding water scarcity, quality, and flooding. We summarized demographics of the respondents for comparison with the 2010 Census and 2013-2017 American Community Survey 5-year estimates for Patagonia to characterize the population of survey respondents.[42,58]

SolVES

The SolVES, Version 3.0 GIS application uses survey response data along with environmental data layers covering a defined study area to provide natural resource managers and stakeholders with spatially explicit outputs of perceived social values.[27,59] SolVES generates statistical models describing the relationship between respondent-provided locations of social value weighted by relative value allocations and the landscape characteristics that potentially explain the geographic distribution and relative intensity of these social values. The result is an output raster dataset, which is a map of the "value index" (a ranking from 0 to 10) that quantifies the relative value of each social value type across a study area.

Version 3.0 of SolVES uses the Maxent maximum entropy model software,[34,60] which uses presence data in the form of respondent-provided point data for various social values. Along with improving SolVES' functionality and accuracy of the results, Maxent allows for the calculation of area under the curve (AUC) statistics using test and training data from the survey points.[59] Training AUC, measuring how well the model fits, and test AUC, indicating the capability of the model to predict socially valued locations, are both calculated.[31,34] AUC values above 0.90 are considered to have a very good fit and predictive power, those from 0.70 to 0.90 a moderate fit and predictive potential, and those below 0.70 a poor fit and predictive power.[31,61] In addition, Maxent also calculates the percent contribution of each variable, which is the sum of the gain from including each variable within each iteration of the training algorithm,[62] and the permutation importance, which represents the contribution of each variable when considered individually after the final model is generated,[62] both calculated as percentages. The SolVES user manual provides a detailed overview of the methodology.[59]

User-defined limitations and layers for SolVES. We formatted the survey responses into a one-to-many relationship between the survey information and the survey points using tabular documents, all linked to a single respondent through a unique identifier called the "Survey_ID." SolVES does not address the points at an individual respondent level but rather at a categorical (social-value type) level. Therefore, SolVES 3.0 weights the points based on the total allotment of points for each of the study points' respective social values.

In addition to survey results, SolVES requires three user inputs: (1) output pixel size, (2) model kernel size, and (3) a set of environmental input variables (see below). The output pixel size is typically defined by the scale of the survey map with the kernel size defaulting to 10 times the output pixel size.[59] For the current study, in which the respondent's map was scaled at roughly 1:175,000, this would correspond to (1) kernel size = 1750 m and (2) output pixel size = 175 m. However, we increased the scale of our analysis to (1) kernel size = 650 m and (2) output pixel size = 50 m. This scale better represents the structure of the landforms within this watershed and uses the environmental variables more accurately within SolVES. In addition, the points were digitized based on geographic knowledge of the watershed and placed at known locations as close to the respondent's designated point as possible. This approach may introduce potential error or subjectivity but may also be more representative of the dynamics of the watershed and allows for a higher resolution analysis.

Spatial variable selection. We included seven input variables in the analysis to characterize landscape properties, aligning with other applications of SolVES.[27,29,63] These variables include (1) Distance to Water (DTW) stream order 4, derived from the U.S. Geological Survey National Hydrography Dataset flowlines layer (hereafter referred to as "streams")[64] (*see below for stream order methodology*); (2) DTW order 3; (3) DTW order 2; (4) DTW order 1; (5) a 10 m Digital Elevation Model (DEM), from the U.S. Geological Survey 3D Elevation Program;[65] (6) slope, derived from the DEM, and (7) 2009 land-use/land-cover (LU/LC).[66] We converted all of the input variables to a raster format and resampled them to a spatial resolution of 30 m, to match the spatial resolution of our most diverse categorical layer, the 2009 LU/LC (Figure 2). We then scaled the environmental variables to 50 m, the output pixel size, within SolVES. Other applications of SolVES have included additional layers such as Distance to Roads (DTR) as well as trails. However, we excluded these variables due to inconsistencies and missing data within the source spatial layers.

Our study area required a multivariate DTW layer because of the associations with the landscape where respondents engage with the Sonoita Creek initially, then extend outwards along the main tributaries, then into smaller tributaries and canyons. The DTW layers were based on stream ordering of the river network, where each unique stream was classified based on its topology and magnitude as a tributary.[67] Starting from the headwaters, tributaries are assigned a value of 1. When two order-1 streams merge, a value of 2 is assigned, and so on, regardless of whether they support perennial stream flow. Sonoita Creek (the primary stream) was assigned the largest value in our study, as a fourth-order stream. In this article, we refer to stream order 4 as Sonoita Creek, while stream order 3 designations will be referred to as the main tributaries.

We input these seven layers with point data for social values collected from respondents. Each respondent's survey points were weighted based on the sum of their social-value allocation and the study area was not buffered in the model.

Quantifying and comparing SolVES results. We quantified social value in two ways: (1) separately to identify areas of high- and low-value index for each social value and (2) as a single summed "heat map," adding all of the social values to identify locations of high and low combined social value. Both approaches can benefit long-term restoration and conservation efforts depending on the restoration objective, either by focusing on a particular relevant social value type or focusing on areas that have high total social value.

Because land ownership/management has been documented to influence human interaction with the landscape,[23,68-70] we also considered social value based on ownership/management boundaries. Our intent was not to use ownership as an explanatory variable, but rather to improve our understanding of how social value is stratified within established ownership boundaries. Therefore, we did not include ownership as an environmental layer within SolVES. Using GIS, we merged the Arizona Ownership layer produced by the Arizona Land Resource Information System (ALRIS) from 2018[71] with the BRN land (Dr. H Ronald Pulliam – BRN, personal communication), TNC land,[52] and the ALWT easements (Janelle Gaun – ALWT, personal communication[53]) to develop a more robust ownership layer. We modified the final ownership layer to adjust misalignments that occurred from integrating all ownership datasets into a single layer, based on the assumption that properties are directly adjacent to each other. We next quantified the

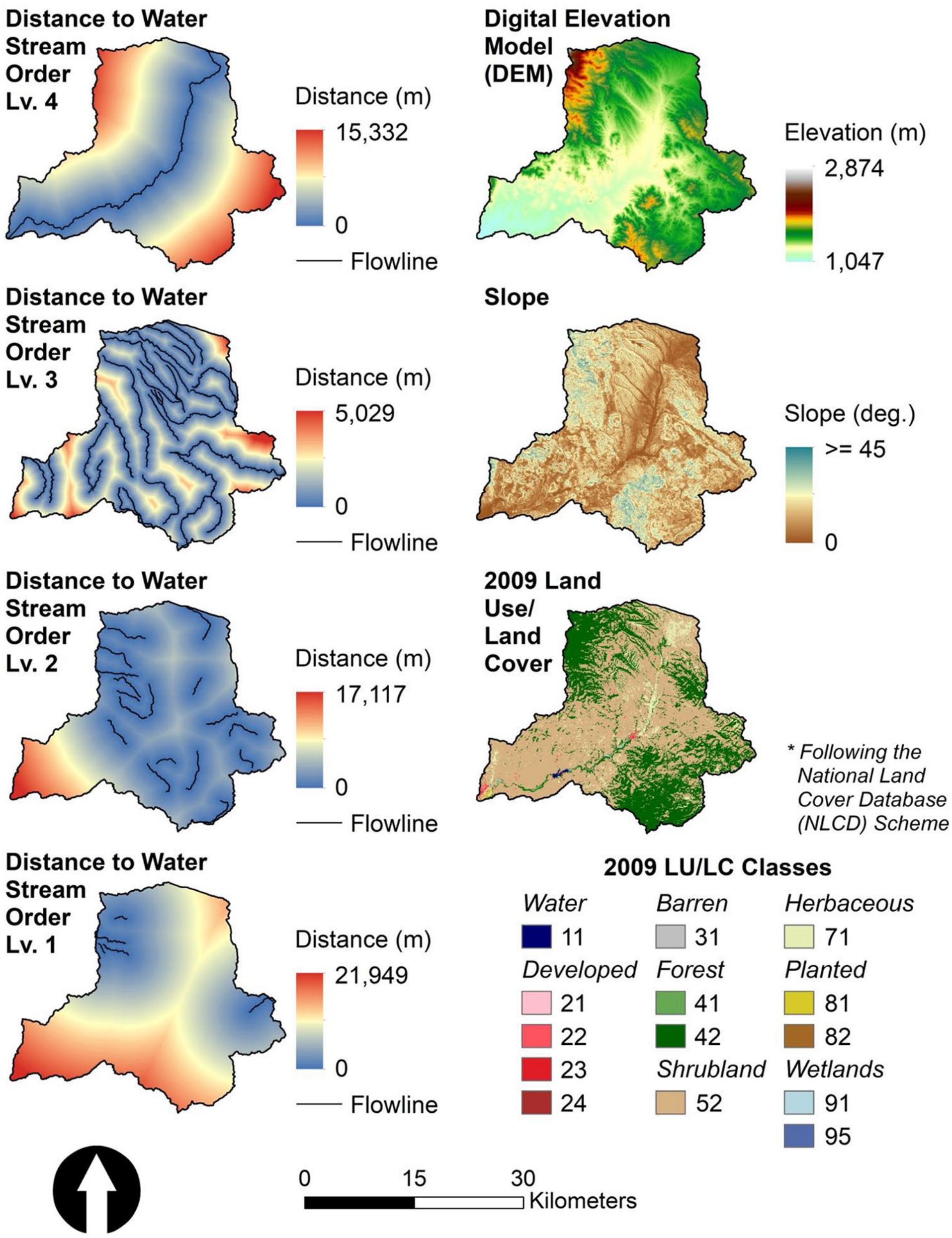

Figure 2. Environmental variables used in the Social Values for Ecosystem Services (SolVES) tool. The 2009 Land Use/Land Cover (LU/LC) class names follow: (Class 11) open water, (21) developed, open space, (22) developed, low intensity, (23) developed, medium intensity, (24) developed, high intensity, (31) barren land (rock/sand/clay), (41) deciduous forest, (42) evergreen forest, (52) shrub/scrub, (71) grassland/herbaceous, (81) pasture/hay, (82) cultivated crops, (91) palustrine forested wetland, and (95) emergent herbaceous wetlands (Villarreal et al[66]).

mean, median, and standard deviation of the summed social value heat map for each ownership boundary using the Zonal Statistics tool in ArcMap 10.5 (Figure 1). We then quantified the same statistics for just the riparian areas, based on a buffered stream within different land ownership/management categories. We developed a 400 m riparian buffer for Sonoita Creek (ie, fourth-order streams—200 m each side) and a 300 m riparian buffer for its main tributaries (ie, third-order streams—150 m each side), based on an estimate of the riparian zone width determined using high-resolution aerial imagery in Google Earth Pro. Second- and third-ordered streams were limited to private, State Trust, and Coronado National Forest lands and were not included in this analysis. We merged the BRN, TNC, and ALWT land into a single category named "conservation management and easement areas" because of their shared management priority for conservation and restoration.

Finally, we validated portions of the SolVES outputs with other datasets that map related characteristics. Although similar products are limited, Villarreal et al[72] developed a spatial biodiversity product for the surrounding region, combining avian, mammal, and herpetofauna richness to represent overall species richness and biodiversity. We compared our SolVES biological diversity and summed social value outputs with this product. We distributed random points and completed a Pearson correlation to measure the relationship between the different products. This analysis can determine whether social

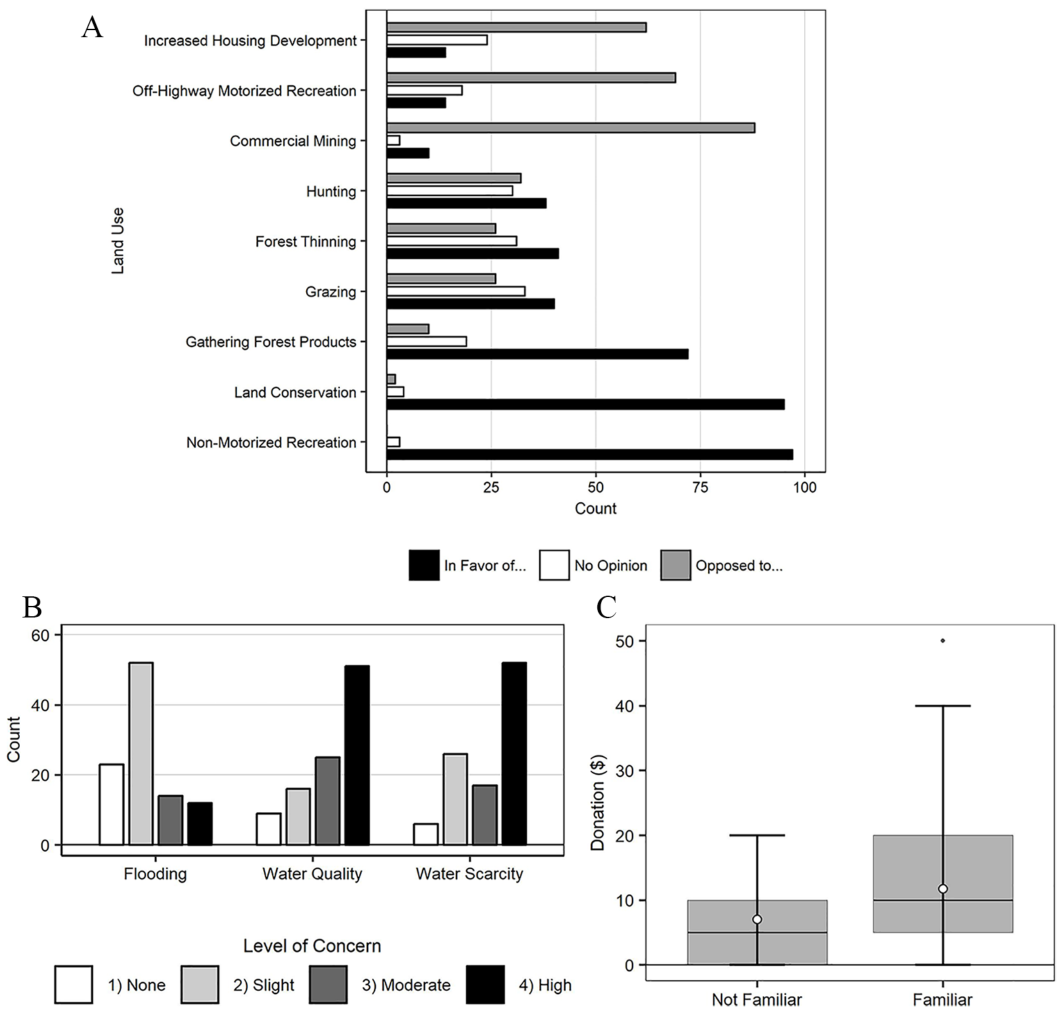

Figure 3. Respondents' opinions related to social and economic engagement with the Sonoita Creek watershed. (A) Opinion regarding different land uses in the watershed. (B) Level of concern about flooding, water quality, and water scarcity. (C) The monthly donation amount with respect to the familiarity to the term "restoration economy."

values for biodiversity mapped by the respondents were similar to modeled species richness or whether the respondents may be considering biodiversity in a different, possibly non-quantitative manner.

Results

Survey data review

In total, we received survey responses from 101 respondents, though not all 101 respondents provided answers for the full suite of questions. The median age of survey respondents (n = 85 of 101) was 68 years, compared to the median age of 49 years in the town of Patagonia.[42] A total of 56.3% of the respondents were female. Education level was not requested in the social survey, but 89.2% of Patagonia's population is a high-school graduate or higher and 32.9% of the population holds a bachelor's degree or higher.[58] The survey population had a median annual income of US$45,000, compared to an estimated US$28,594 for Patagonia.[58] The surveyed population was thus generally older and earned more income than the median resident of Patagonia; women were overrepresented in the survey population.

The majority of respondents opposed intensive land uses, including commercial mining (n = 88), off-road motorized recreation (eg, ATVs; n = 69), and increased housing development (n = 62; Figure 3A). Lower impact land uses and those that connect humans with the landscape were generally approved of, such as gathering forest products (eg, mushrooms, household fuelwood; n = 72), land conservation (n = 95), non-motorized recreation (eg, wildlife viewing, hiking; n = 97). Intermediate-intensity land uses that cause limited disturbance to the landscape (eg, hunting, forest thinning, and grazing) were generally split "in favor of" and "opposed to" by the respondents.

Overall, there was relatively higher concern related to water quality and scarcity with a majority of the respondents being highly concerned with those water threats (n = 51 and 52 of 101, respectively; Figure 3B). As with results of any survey, this may reflect bias due to the selection of citizens who responded. However, concern for flooding was low with most of the respondents selecting it to be of "slight concern" (n = 52).

Table 2. Statistical values from the SolVES model, including *R*-value and *Z*-score, indicators of clustering, and training and test AUC statistics, indicating the fit (training) and predictability (test) of the model.

SOCIAL VALUE	COUNT	*R*-VALUE	*Z*-SCORE	TRAINING AUC	TEST AUC	MAXIMUM VALUE INDEX
Life Sustaining	67	0.331	−10.470	0.906	0.907	10
Biological Diversity	89	0.348	−11.762	0.889	0.861	8
Aesthetic	101	0.289	−13.662	0.884	0.816	7
Future Generations	64	0.394	−9.267	0.880	0.915	6
Recreational	108	0.325	−13.426	0.891	0.868	6
Economic	34	0.599	−4.470	0.951	0.915	5
Therapeutic	69	0.355	−10.258	0.888	0.710	5
Historical	48	0.484	−6.843	0.932	0.807	4
Intrinsic	58	0.410	−8.601	0.891	0.862	4
Spiritual	59	0.396	−8.874	0.881	0.852	4
Cultural	22	0.622	−3.393	0.950	0.933	3
Learning	43	0.523	−5.983	0.920	0.835	3

Finally, the maximum value index indicates the relative importance of the social value to the respondents.
Abbreviations: AUC, area under the curve; SolVES, Social Values for Ecosystem Services.

Finally, if the respondent was familiar with the term "restoration economy," they were willing to donate (WTD) more money per month, on average, to a community water fund that would invest in a preferred management activity (Familiar: n = 89, mean WTD of US\$11.76; Not familiar: n = 7, mean WTD of US\$7; Figure 3C). In combination, these results show that respondents favor land uses that have limited impact to the landscape and may even improve the respondent's personal experience with the landscape, such as land conservation. The respondents show concerns regarding both water scarcity and water quality and have a willingness to invest in a restoration economy, particularly those who are aware of the concept. These results emphasize social, emotional, and economic investment in the watershed.

SolVES model results

In total, 42 of the 101 respondents completed the mapping portion of the social survey. This aligns with other studies using SolVES, where fewer respondents typically complete the mapping exercise than the other survey questions.[27] A total of 59 different locations were mapped, with 762 points representing a combination of all 12 social values. On average, 18.1 points were placed by each respondent.

All 12 social values were relatively clustered (ie, negative *Z*-scores; *R*-values closer to 0 than 1) with the highest clustering occurring for social values that had higher counts or greater presence across the landscape (aesthetic, recreational, and biological diversity—Table 2). Several social values had training and/or test AUC values greater than 0.9, indicating good fitting models (test AUC) with good predictive power (training AUC; eg, life sustaining, future generations, economic, historical, cultural, and learning). All other training and test AUC values were between 0.7 and 0.9, indicating a moderate model fit and predictive power. The maximum value index ranged from 3 to 10 across the social values; life-sustaining value had the highest maximum value index (10), followed by biological diversity (8), aesthetic (7), future generations (6), and recreational (6) (Table 2). This indicated high relative importance of these values. Meanwhile, learning, intrinsic, historical, and spiritual value had the lowest maximum value index, ranging from 3 to 4, indicating lower relative importance to the respondents.

The percent contribution and permutation importance for each environmental variable can indicate the relative importance of the variable in the model for each social value (Table 3). The 2009 LU/LC environmental variable had the highest percent contribution for 9 of the 12 social values and was second highest for the remaining three social values. However, the permutation importance for the 2009 LU/LC was generally below 10%. The 2009 LU/LC was thus not necessarily a substantial standalone variable but was valuable as a contributing variable. The DTW 3 variable was an important contributor to all models except for the economic and cultural social values. This implies that distance from the main tributaries is an important factor for nearly all of the social values. The topographic variables—DEM and slope—generally had mixed results. The DEM had higher permutation importance than percent contribution for all values. Slope was a particularly important contributing variable for the cultural (24.9%) and historical (32.2%) social values.

In general, there was a disconnect between the respondents' mean assigned point value for certain social values and their engagement with the landscape (Table 4). For instance,

Table 3. Percent contribution (Cont.) and permutation importance (Imp.) for each social value and input environmental variable (%).

SOCIAL VALUE	VARIABLE	DTW 4	DTW 3	DTW 2	DTW 1	DEM	SLOPE	2009 LU/LC
Life Sustaining	Cont. (%)	4.7	25.0	11.0	2.0	4.0	16.5	36.8
	Imp. (%)	0.0	26.9	30.0	10.6	23.9	2.2	6.4
Biological Diversity	Cont. (%)	13.1	30.3	9.6	3.2	2.5	10.2	31.2
	Imp. (%)	0.2	31.2	24.9	21.6	14.1	1.4	6.6
Aesthetic	Cont. (%)	11.5	24.3	13.2	5.4	3.6	14.1	27.8
	Imp. (%)	0.0	16.8	31.9	17.0	29.1	1.4	3.7
Future Generations	Cont. (%)	22.5	11.6	8.1	0.2	3.1	4.1	50.5
	Imp. (%)	1.1	20.3	36.9	4.1	30.6	1.0	6.0
Recreational	Cont. (%)	17.0	29.9	13.3	5.3	2.6	6.9	25.0
	Imp. (%)	13.2	21.3	35.1	10.5	7.4	6.5	6.1
Economic	Cont. (%)	10.0	4.6	8.3	0.1	2.1	12.0	62.8
	Imp. (%)	3.0	22.9	44.8	3.3	18.9	2.5	4.5
Therapeutic	Cont. (%)	3.3	38.2	15.6	1.0	1.1	8.7	32.1
	Imp. (%)	0.0	30.1	27.5	5.8	21.4	3.4	11.7
Historical	Cont. (%)	4.2	15.0	8.8	2.2	3.4	32.2	34.2
	Imp. (%)	1.8	23.0	21.7	8.4	27.1	10.6	7.3
Intrinsic	Cont. (%)	11.1	43.6	8.9	2.2	3.3	5.7	25.2
	Imp. (%)	0.0	41.1	23.4	8.9	13.1	3.0	10.6
Spiritual	Cont. (%)	21.8	20.9	8.8	0.6	3.7	16.2	28.1
	Imp. (%)	18.5	25.3	29.5	4.8	10.3	6.0	5.5
Cultural	Cont. (%)	1.9	3.1	9.9	0.6	4.3	24.9	55.3
	Imp. (%)	0.0	6.1	46.8	1.1	35.5	2.3	8.2
Learning	Cont. (%)	14.9	27.0	14.1	0.8	3.5	2.0	37.7
	Imp. (%)	0.0	28.5	18.2	2.5	41.5	0.0	9.3

Abbreviations: DEM, Digital Elevation Model; DTW, distance to water; LU/LC, land-use/land-cover.

Table 4. Mean assigned point value for each social value (0 to 100 possible points).

SOCIAL VALUE	MAXIMUM VALUE INDEX	MEAN ASSIGNED POINT VALUE	PERCENTAGE OF STUDY POINTS (%)
Life Sustaining	10	20.3	46
Biological Diversity	8	16.4	61
Aesthetic	7	16.8	69
Future Generations	6	18.3	46
Recreational	6	14.6	73
Economic	5	9.8	27
Therapeutic	5	13.4	53
Historical	4	9.6	42
Intrinsic	4	14.2	53
Spiritual	4	10.2	61
Cultural	3	7.7	25
Learning	3	7.2	39

The percentage of study points refers to the number of study points that were assigned the particular social value with respect to the 59 total study points where respondents assigned social values.

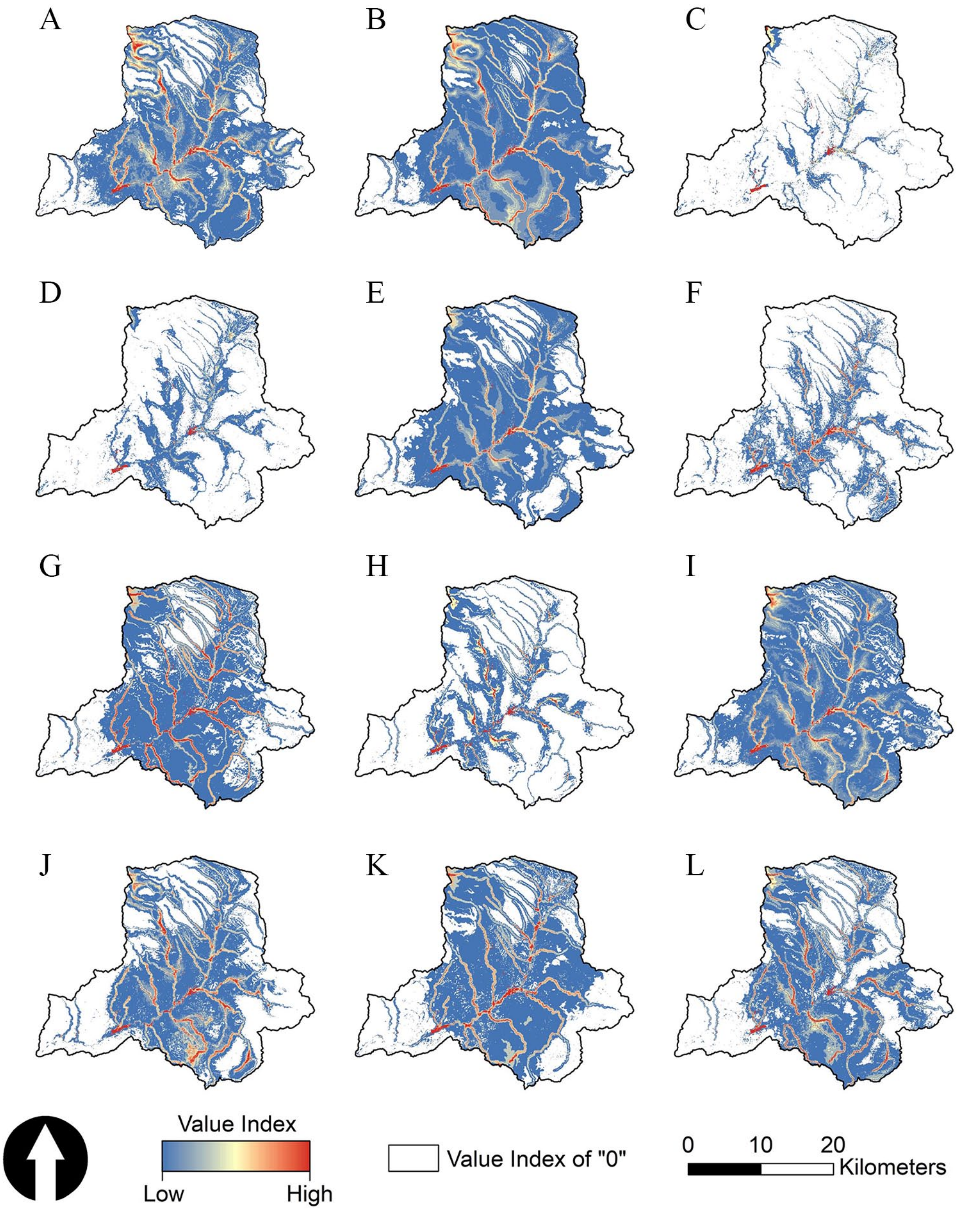

Figure 4. Relative spatial variation in value index for each of the 12 social values across the study area, ranging from 0 (white), to low (blue), to high value (red). A. Aesthetic. B. Biological Diversity. C. Cultural. D. Economic. E. Future Generations. F. Historical. G. Intrinsic. H. Learning. I. Life Sustaining. J. Recreational. K. Spiritual. L. Therapeutic.

respondents listed recreational value at more of the 59 total study points than they did for life-sustaining value (73% and 46% of study points, respectively), but the respondents assigned lower point values, on average, for recreation than life-sustaining value (14.6 and 20.3, respectively). Similarly, future-generation value had the second highest mean point value (18.3) but was assigned to only 46% of the study points by the respondents. In contrast, there was a greater percentage of study points placed to represent spiritual value (61%) but mean assigned point value was low (Table 4). Generally, social values that address the future quality and environmental aspects of the watershed had higher mean point values than for social values that represent the respondent's emotional connection with the watershed, such as historical, cultural, and learning values (all with mean assigned point values below 10).

The corresponding social value maps showed the location of low and high values for each social value ranked and mapped by the respondents (Figure 4). For the cultural (4c), economic (4d), historical (4f), and learning (4h) social values, a large portion of the watershed had a value index of 0. However, areas of higher value were centered along Sonoita Creek and its main tributaries, particularly within the town of Patagonia and surrounding Patagonia Lake (Figure 1). The other social values had more widespread value index results focused within the center of the watershed but also reaching north toward Mt. Wrightson and Sonoita as well as southeast toward the San Rafael Valley Rd. Recreational Areas (Figure 1). The biological diversity (4b) and life-sustaining (4i) social values had measured value index results across the largest portion of the watershed. The aesthetic (4a), future generations (4e), and

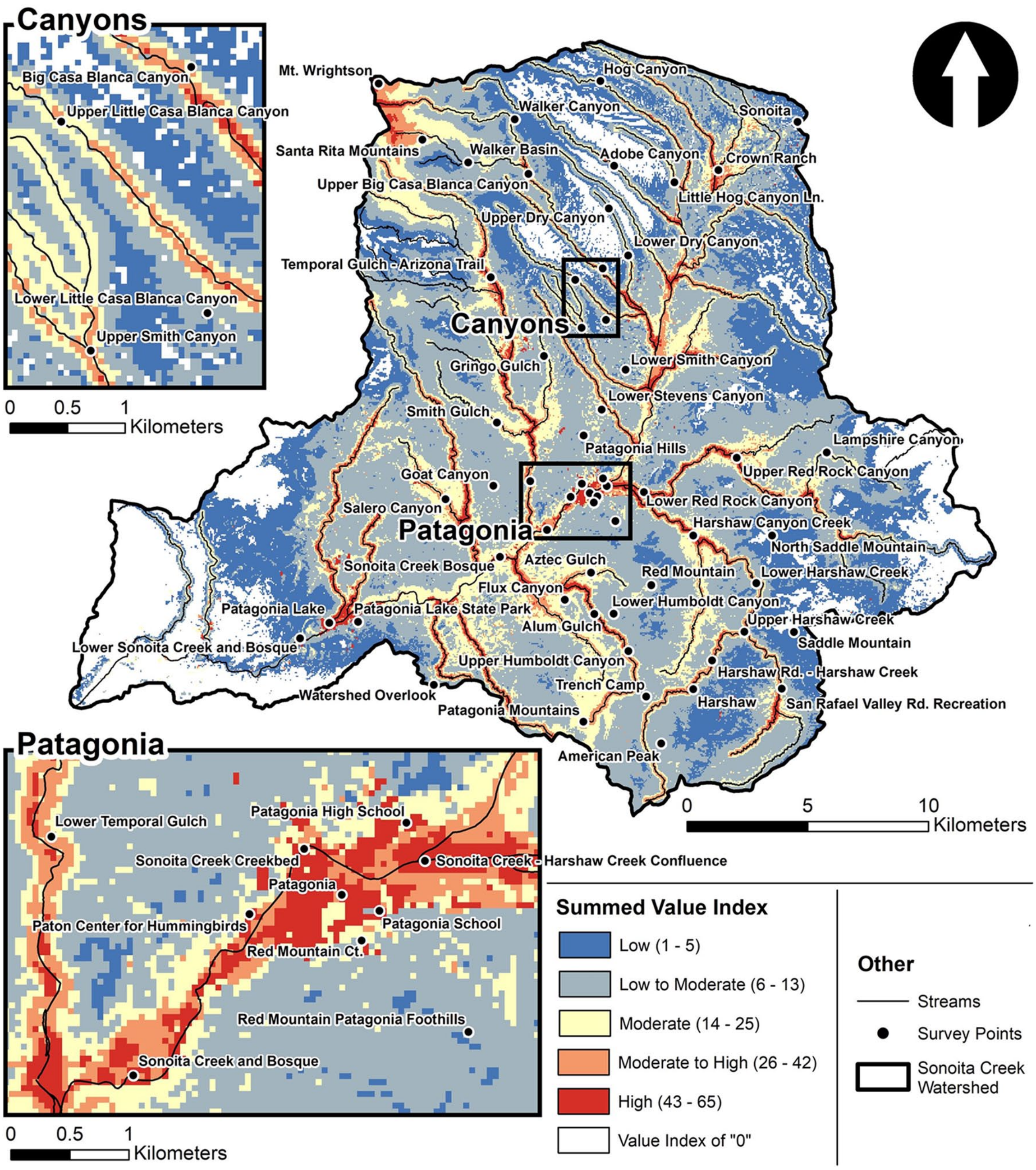

Figure 5. Summed social values, divided into classes using natural breaks, with our master list of locations (n = 59) denoted. Red areas had the highest summed value, while blue had the lowest summed values. White areas had a summed value index of 0.

recreational (4j) social values had a higher maximum value index, 6 or above (Table 2), but their mapped value was generally centered within ~10 km around the town of Patagonia, as well as around Mt. Wrightson and along Sonoita Creek (Figure 1).

Generally, the highest combined value index favored Sonoita Creek and its main tributaries (Figure 5). The areas directly surrounding Patagonia were also highly valued, as well as portions of the Santa Rita Mountains including Mt. Wrightson. Within the southern half of the watershed, streams along Harshaw Creek, Red Rock, Flux, Salero, and Humboldt Canyons and Temporal Gulch had particularly high collective value. Transitional areas between the streams, consisting of hills and grasslands, had a lower collective value index, particularly in the north, west, and southwest portions of the watershed where a summed value index of 0 was observed. A USGS Data Release including the twelve social value maps and the combined value index map can be found on ScienceBase (https://doi.org/org/10.5066/P98B4B1X).

Stratification by ownership and biodiversity comparison

Summed social values varied based on ownership/management boundaries. The PLSP had the highest mean summed social value of all land ownership classes for all three focus areas

Table 5. Zonal statistics for summed social values by land ownership type.

OWNERSHIP	FULL BOUNDARY			SONOITA CREEK RIPARIAN BUFFER			MAIN TRIBUTARY RIPARIAN BUFFER		
	MEAN	MEDIAN	STANDARD DEVIATION	MEAN	MEDIAN	STANDARD DEVIATION	MEAN	MEDIAN	STANDARD DEVIATION
Conservation Management and Easement Areas	16.3	12	11.9	30.8	25	14.8	33.5	32	13.5
Coronado National Forest	9.7	8	9.1	n/a	n/a	n/a	23.1	21	12.6
Arizona Game and Fish	4.8	3	7.0	n/a	n/a	n/a	34.1	35	10.2
Patagonia Lake State Park	36.0	33	25.5	49.4	65	20.7	53.0	56	13.7
Private Land	11.8	8	12.5	19.9	16	16.8	29.9	29	15.0
Sonoita Creek State Natural Area	2.7	0	5.4	4.2	2	7.0	12.7	11	8.5
State Trust Land	9.2	8	8.2	14.9	14	10.6	37.5	38	13.8
Non-bounded	10.3	8	10.6	21.6	17	18.3	25.4	23	14.0

Buffers were 400 m for Sonoita Creek and 300 m for the main tributaries, reflecting the estimated extent of riparian areas.

(Table 5). The merged conservation management and easement areas had the second highest mean values for both the full boundary and Sonoita Creek riparian buffer, values that were higher than on private land. Arizona Game and Fish and State Trust Lands had much higher mean values for the main tributary riparian buffer areas when compared to the full boundary and Sonoita Creek riparian buffer. The Sonoita Creek State Natural Area had the lowest mean value, lower than both the overall and private land mean values. The Coronado National Forest also had generally low value, with increased value along the main tributaries; however, both values were lower than the mean for non-bounded areas. Finally, the main tributary riparian buffer had an overall higher mean value than the Sonoita Creek riparian buffer when not stratified by ownership (Table 5).

The relationships between the biophysically modeled species richness data and the modeled SolVES social value for biological diversity ($R^2 = 0.07$, P value = .002) and summed social value ($R^2 = 0.10$, P value < .001) were both significant but variable with low R^2 values, signifying moderate fit with low predictive power. Overall, the public did not necessarily relate biological diversity as they perceived it using the social survey with high areas of modeled species richness.

Discussion

Interpreting the survey and SolVES results

Through the survey data, we learned about the preferences, concerns, and level of engagement that the respondents had with the Sonoita Creek watershed. According to Theobald et al,[19] ecological data and analysis must be understood by those who will be affected by the decisions, in this case, survey respondents who use these landscapes. Overall, the respondents' willingness to invest in ecological restoration based on their knowledge of a restoration economy (Figure 3C) combined with interest in conservation and other low-intensity/recreational land uses (Figure 3A) indicate that they are socially and economically invested in an active restoration economy. Respondents also showed knowledge of their surrounding ecosystem through their social value point placement, highlighting places in the watershed that they consider to be important while showing widespread awareness for recreation, aesthetics, biological diversity, and spiritual value (Table 4).

However, we must also consider that the respondent population is a specific demographic of Patagonia and may show more interest in conservation and issues of water than the general resident of the watershed. This effect is common with smaller sample populations,[73] and participation bias may be present within various sociodemographic variables.[74] Generally, participants of PPGIS studies are older with higher incomes—similar to the survey population in this study. An older population may be more concerned about the future of the watershed than its current state. Deviation in income may influence the desired activities of participants;[75] similarly, participant knowledge of the study site also will influence the amount of spatial information provided by the respondent.[73,74] Limited SolVES studies have directly compared survey demographics to the demographics of the study site population, but van Riper and Kyle[76] found that—within the survey population—age, income, and ethnicity did not vary between groups who were in equal agreement of both biocentrism and anthrocentrism and those who favored either. In consequence, those less interested or informed on conservation and restoration may not complete or return the survey. In addition, representing a more affluent population, the respondent demographic may have a greater capacity to donate as well as a greater ability to be directly engaged with restoration or conservation efforts. We acknowledge that error may be generated due to the survey responses, making results of SolVES analysis contingent.

Respondents showed concern regarding both water quality and scarcity. These variables are potentially impacted by the key environmental challenges facing residents of the watershed, including changing climate,[77] contamination from *Escherichia coli* bacteria[78] or acid-mine drainage,[79,80] and regional population growth.[81] Various watershed restoration techniques, such as in-channel structures including gabions and check dams, can improve water quality and availability and reduce erosion.[82-86] They can also promote vegetation growth in the surrounding area and downstream of the structure.[87,88] The development of a restoration economy that supports these restoration techniques may be important in improving water quality and availability, particularly along streams and perennial water sources where social values are perceived to be the highest.

Overall, high perceived social values were clustered near the streams, with higher values along Sonoita Creek's main tributaries. We hypothesize that access to these locations and landscape features, such as topographic structure and proximity to the streams, were likely driving factors in respondents' placement of locations that they value on the map. Sonoita Creek and its tributaries have significant ecological and social value in the Southwest U.S., serving as intermittent and ephemeral water sources.[89] With features such as the Arizona Trail and roads that run along streams where water is occasionally present with increased tree cover, including San Rafael Valley Rd., Harshaw Creek, Big Casa Blanca Canyon, and Temporal Gulch, among others (Figure 5), respondents engage with these locations specifically and more often than other areas along Sonoita Creek or upland areas. We presume the respondents placed the points in areas that are familiar to them.

We observed two important findings about land ownership/management. First, considering social value in a landscape with diverse ownership and management objectives provides challenges and important caveats.[70] For instance, PLSP and the Sonoita Creek State Natural Area (SCSNA) are both state-managed parks with substantially different mean summed social values (PLSP = 36; SCSNA = 2.7). If combined as "state parks," our assessment of social value within PLSP would appear to be substantially lower, reducing the overall impact of that location within our analysis. The rare access to perennial water at PLSP within an arid landscape likely influences social values results upward for PLSP.

Second, the conservation-based areas had higher mean social value compared to private land, implying that the conservation efforts being applied in these areas may increase the value of these locations if they enhance ecological qualities that are valued by respondents. However, access to and knowledge or awareness of these areas is essential in a social survey analysis where the respondents placed the survey points based on their knowledge of the watershed. In other words, areas with limited public access, even if ecologically important, might be expected to have lower values. The lower social value for the Coronado National Forest and other state-managed lands may suggest these areas are used less by the respondents or that either the survey or the SolVES model did not address the value of forests as a land cover type well enough. Access to these areas is also more limited due to the quality and number of roads beyond the area immediately surrounding Sonoita Creek. Access to private lands is similarly limited. Overall, identifying certain areas with increased social value (ie, conservation areas) does not necessarily indicate that these areas are more valuable than others within an active restoration economy nor the best place for restoration, but rather highlights their current recognition.

Finally, our results about the relationship between modeled species richness and biodiversity value align well with a similar study by Bagstad et al[32] for the Pike-San Isabel National Forest in the Rocky Mountains of southern Colorado. That study similarly found a very weak relationship ($P = .058$, adjusted $R^2 = 0.011$) between biodiversity quantified using species distribution model results aggregated to produce a species richness dataset and biodiversity values elicited from a survey of the public and modeled using SolVES. Brown et al[90] note that "While few would question the validity of using PPGIS to generate maps for identifying cultural ES, many would question the utility of consulting the 'public' to identify more complex and 'invisible' ecosystem services (p. 647)," such as biodiversity. This disassociation between increased social value and true biodiversity may be an important consideration in future restoration-based activities.

SolVES challenges and considerations for future application

The users of these results (eg, natural resource managers, researchers, residents) should consider that there are aspects of PPGIS analyses, including SolVES, that have a definitive impact on the results but are either highly variable or cannot be independently isolated in the model. First, there are challenges with scaling due to the kernel size. Our kernel size was based on landscape definitions where streams are located within sub-canyons surrounded by upland hills. SolVES will consider all points with respect to their immediate surroundings based on the input kernel size, despite inconsistencies in intended spatial scale of the perceived point. This may have intensified the impact of the stream variables, where a majority of the points were located. Second, it is imperative to select spatial layers that accurately represent how the respondents connect with and visualize the landscape.[91] Our multi-variate DTW layers allowed for a more accurate representation of how the respondents engaged with certain streams based on their landscape characteristics and proximity to Sonoita Creek. This approach also helped us avoid producing output products in which all streams had similarly high value, which is not accurately representative of how respondents placed points. Third, having the respondent name the points or locations to which they associate social values with could greatly increase the accuracy of this approach. The analyst could then digitize the location each respondent intends to highlight without making assumptions of how well the study site map aligns with respondents' geographic knowledge of the area.

Although a direct quantitative comparison with other SolVES studies may be challenging due to variations in the social survey data and points as well as the environmental variables that were included, a qualitative review of the spatial aspects of social value between different studies is warranted.[92] For instance, many climate and environmental threats are uniform across different spatial scales and locations, but unique partnerships formed by different people to address these challenges can provide more effective solutions overall.[70] Future applications of SolVES for different watersheds across the southwestern U.S. and Madrean Archipelago could provide an understanding of regional differences or similarities, advancing our scientific understanding of how people value the landscape and ultimately providing relevant information for managing natural resources within the region.

Developing a respondent-defined restoration economy

Numerous methods can be applied to quantify ES, including SolVES.[93,94] Our results can help inform land managers of the spatial properties of social values to inform the further development of a restoration economy, which are the initial steps in producing quantifiable ES, as described by Daily et al.[95] We discuss two opportunities in which our results can be used to develop a defined restoration economy in the region.

First, the SolVES results have the potential to provide a structure highlighting where to invest. Despite the many applications of SolVES for data development, there is not currently a research example of SolVES being used in a real-world decision context; hopefully, this study can be the first. Tallis and Polasky[96] discuss how a similar spatial ES model (InVEST) has been used effectively within a decision-making process for natural resource management. Determining how and where to invest through public and private partnerships, including currently active efforts (eg, BRN, TNC, private investments, Forest Service, and state lands), but incorporating SolVES outputs is a possible next step. The main contrast between these approaches is that biophysical models like InVEST generally quantify ES based on underlying biophysical processes, while SolVES and other PPGIS approaches focus primarily on cultural ES. Biophysical models and PPGIS can be combined to yield additional insights for management.[23,32] Additional factors can challenge the application of ES, including the scale of the project—both temporally and spatially.[97] Misalignments between hotspots of certain social values and the overall summed social value output suggest that specific investments should consider the intended impact of restoration activities and their effect on specific social values. Additional considerations of funding availability and the willingness to engage in restoration efforts provide additional challenges and relevant factors in conservation and restoration decision making.

Second, when investment is not possible, or to extend the scale of restoration efforts, the SolVES results suggest opportunities to educate the population to protect and conserve land based on how the results are expressed on the landscape. For instance, educating the residents on the value of PLSP and the primary streams in the watershed can help build the constituency to support conservation of those lands.

Conclusion

Explicitly mapping spatial properties of ES can support a restoration economy that focuses investments where the highest social values are perceived across the landscape. We applied the SolVES model within the Sonoita Creek watershed, Arizona, USA, to develop a spatial representation of quantitative social values elicited from a social survey. Established riparian areas had the highest value across the watershed for all 12 of the social values that were surveyed, particularly within the Patagonia area, certain state parks, limited Forest Service lands, and known perennial streams and their main tributaries. Land ownership and management also appeared to guide where the highest perceived value occurred. Organizations holding land (or easements) for conservation typically have higher mapped values than privately owned lands to respondents of the social survey. However, PLSP had the highest mean social values, while the surrounding National Forest lands had lower mean values than the overall watershed. Through this analysis, a respondent-defined restoration economy can be developed that targets investments in locations that are important to those who value and connect with the Sonoita Creek watershed's landscape and ecosystems.

In addition, results show how respondents engage with the landscape individually and distinctively for each of the 12 social values, as well as support conservation and restoration investments, based on their knowledge of the concept of a restoration economy. The respondents of this survey portray an older generation, who have familiarity with restoration economy and seem to welcome the ES that are promoted when a community places emphasis on conservation of lands. Life-sustaining, biological diversity, and aesthetic values are the most important social values recognized by our survey population. Recreational areas and places that benefit future generations followed closely in value. Future investment in ES could be built on the goal of enhancing these values. Finally, it is apparent that respondents who have awareness in respect to the returns of investing in landscape conservation, indicated by their knowledge of the term restoration economy, are more interested to be invested themselves. This suggests that teaching and communicating goals in landscape conservation may result in a win-win for the environment and the people who live there.

Acknowledgements

We thank the citizens of the Sonoita Creek watershed for providing us with local knowledge. Thanks to Dr. Kelly Mott-Lacroix (USFS) and Dave Ellis (BRN) for their initial reviews of the survey. Finally, we appreciate the internal review of this manuscript done by Drs H. Ronald Pulliam (BRN) and William Labiosa (USGS) as well as the two anonymous reviewers provided by the journal. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Author Contributions

This study and associated manuscript was done in partnership with all the authors. REP modelled the data, developed results, interpreted results and data, and wrote portions of the manuscript. LMN developed the research, designed methods, assisted in interpretation of results, and wrote portions of the manuscript. OL delivered the survey instrument, collected survey responses, and helped edit and wordsmith the paper. BCS, DS, and KJB provided expertise in use of the SolVES model, as well as helped devise and revise corresponding portions of the manuscript. RP was involved with the initial development and funding of the survey. All authors read and approved the final manuscript.

ORCID iD

Roy E Petrakis https://orcid.org/0000-0001-8932-077X
Laura M Norman https://orcid.org/0000-0002-3696-8406

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