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ORIGINAL ARTICLE

Understanding social–ecological vulnerability with Q-methodology: a case study of water-based ecosystem services in Wyoming, USA

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Abstract A broad range of participatory methods can be employed to understand the vulnerability of social–ecological systems threatened by various drivers of change including climate change and land-use change. Understanding this vulnerability is critical for managing natural resources, particularly water resources that flow across jurisdictional boundaries, and support conflicting uses. This paper demonstrates Q-methodology, a promising participatory method infrequently applied in the vulnerability context, with a case study investigation of the vulnerability of stakeholders reliant on water-based ecosystem services derived from the Shoshone National Forest in Wyoming, USA. The approach identified four distinct viewpoints regarding vulnerability, including an environmental perspective, agricultural perspective, Native American perspective, and recreation perspective. The distinct viewpoints highlighted disparate levels of importance related to 34 water benefits, such as commercial irrigation, oil and natural gas extraction, river-based fishing, and cultural and spiritual use. A diverse range of drivers of change threatening important water benefits were also identified, including pollution, too much management intervention, and development of recreation opportunities. The potential benefits of Q-methodology for vulnerability assessment include a rank-ordering exercise that elicits preferences for tradeoffs, and statistical derivation of a small number of perspectives about the topic.

Keywords Ecosystem services · Social vulnerability · Stakeholder involvement · Q-sort · Factor analysis · Q-method · Integrated vulnerability assessment

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Introduction

The integrity of social–ecological systems (SESs) around the world is threatened by numerous stressors (e.g., climate change, land-use change, and invasive species), and research is revealing that such stressors are likely to cause abrupt and potentially irreversible changes that have serious consequences for human well-being (MEA 2005; IPCC 2007, 2012; Advisory Committee for Environmental Research and Education 2009). SESs are inherently complex and interconnected, and the relatively new field of sustainability science focuses on providing holistic (i.e., multidisciplinary, transdisciplinary, and interdisciplinary) approaches that aim to understand the dynamic linkages between nature and society to support the development of sustainable adaptations, environmental management, and policy recommendations in the face of uncertainty (Gallopín et al. 2001; Clark and Dickson 2003; Kajikawa 2008; Stock and Burton 2011).

Of central importance within sustainability science is the need to understand the characteristics of SESs that affect their vulnerability in the context of global environmental change (Kates et al. 2001; Turner et al. 2003; Turner 2010; Gabrielsson et al. 2013). Vulnerability assessments aim to

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measure possible future harm to SESs by understanding susceptibility, and describing both the current state of systems and possible future scenarios as they relate to important variables of concern that are at risk of being affected by a multitude of drivers (Adger and Kelly 1999; Adger 2006; Carter et al. 2007; Hinkel 2011; Wolf 2012). Susceptibility is a function of exposure, sensitivity, and adaptive capacity; where exposure refers to the likelihood that a driver will have repercussions on a system, sensitivity focuses on the degree to which a system will respond to an external driver, and adaptive capacity refers to a system's ability to evolve, both through shock absorption and self-organization (Luers 2005; Adger 2006; Metzger et al. 2008; Engle 2011; Fischer et al. 2013).

In order for vulnerability assessments to be relevant to local decision-makers, Luers (2005) stressed that they need to include the potential impact of particular drivers of change (e.g., over-fishing, land-use change, or climate change) on specific variables of concern (e.g., ecosystem services) that are tied to human and environmental well-being. It has been argued that no resource will be more critical to human health and well-being than water in the coming decades, and that no region in the world is more cognizant of the current water crisis than the western United States (National Research Council 2004; Hundley 2009). Decision- and policy-making regarding water in the western United States is especially difficult when considering the competing nature of several water benefits (e.g., agriculture and instream flow for environmental use), and the fact that humans place disparate values on a wide range of benefits that are reaped at various spatial and temporal scales. As a result, choices made by managers and policymakers will result in tradeoffs and, consequently, 'winning' and 'losing' stakeholders.

Assessing the vulnerability of inherently complex social–ecological systems requires the consideration of multiple variables and drivers (economic, cultural, demographic, and environmental) (Turner et al. 2003; Adger et al. 2009; Bennett et al. 2016). To this end, vulnerability assessments are increasingly incorporating the ecosystem services concept, because, it can effectively illustrate how natural resources contribute to the well-being of humans (Kumar et al. 2011; Stratford et al. 2011; Micheli et al. 2014). Ecosystem services' contribution to human well-being is complex, as it depends on spatial scales, levels of dependence, a combination of utilitarian and non-utilitarian values, and issues of access (Zhang et al. 2014). However, to advance beyond a broad and conceptual understanding of how ecosystem services support human well-being, to a nuanced and local understanding, it is likely that process information will need to be collected. That is, information that "concerns the relations among people and organizations and between people and landscapes that influence people's perceptions of their own well-being and capacity to act" (Fischer et al. 2013: 361).

In the context of vulnerability, a broad range of participatory methods for collecting process information have been employed, including focus groups and stakeholder meetings (e.g., Parkins and MacKendrick 2007; Plummer et al. 2013), one-on-one qualitative methods such as individual interviews (e.g., de Chazal et al. 2008; Farley et al. 2011; Kaján 2013), a combination of focus groups and one-on-one meetings (e.g., Eakin 2005; Keskitalo 2008; Gabrielsson et al. 2013), GIS mapping tools (e.g., Hung and Chen 2013), fuzzy cognitive mapping (e.g., Reckien et al. 2013), and normative visions (e.g., Schneider and Rist 2014). Although Q-methodology has rarely been employed to understand vulnerability (see Albizua and Zografos 2014 for the only published application), the method provides several benefits such as highlighting agreement, disagreement, and ambivalence regarding the topic of interest via a rank-ordering exercise, statistically reducing numerous unique perspectives into a limited number of general perspectives, and providing a nuanced understanding of general perspectives supported by process information. Assessing vulnerability with Q-methodology can facilitate an understanding of the complex nature of the contribution of ecosystem services to human well-being. Such an understanding is critical for "measuring, modeling, valuing and managing ecosystem services" (Zhang et al. 2014: 89).

This paper presents an application of Q-methodology to understand the social–ecological vulnerability of stakeholders reliant on water-based ecosystem services (WESs) derived from the Shoshone National Forest (SNF) in the state of Wyoming, USA. This understanding was gathered by collecting process information regarding how water flowing from a protected federal area supports well-being, the potential drivers of change threatening that well-being, perceived capacity to adapt, and the likely tradeoffs associated with changes in flows of WESs. Also, the potential of Q-methodology as an approach to understand social–ecological vulnerability is discussed.

Study area

The purpose of this research was to inform national forest managers and policymakers about the vulnerability of stakeholders reliant on water flowing from the SNF to complement a top-down assessment of biophysical vulnerability of water resources flowing from the SNF by Rice et al. (2012). Similar to many landscapes in the western United States, the study area (Fig. 1) has: a snow-driven hydrologic cycle, variable topography, vegetation and climate, federally protected land with headwater streams supporting both forest users and downstream communities,

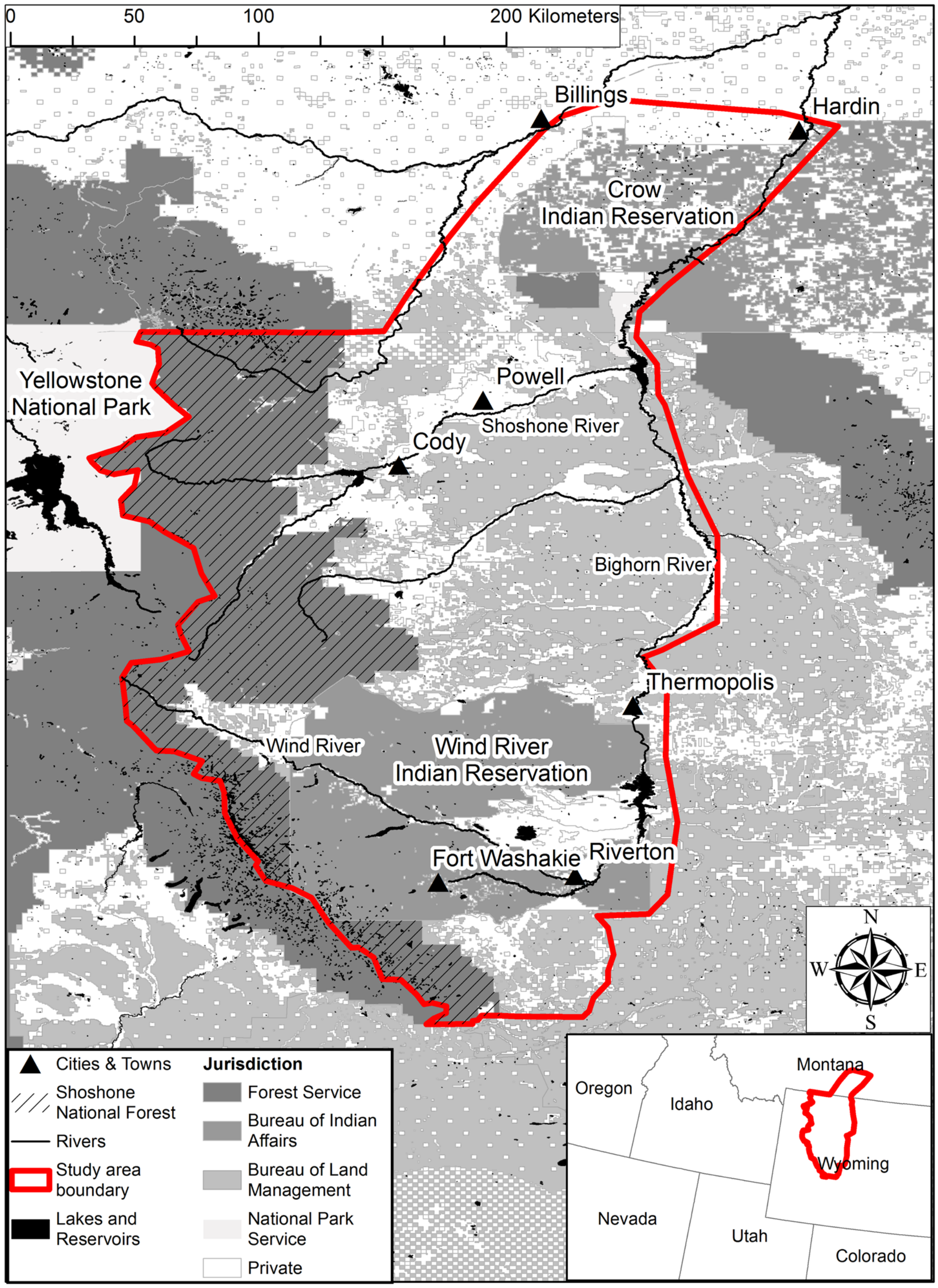

Fig. 1 Study area map

natural resource-driven economies, and a sense of place dating back generations.

The SNF protects a number of headwater streams, which flow from high elevation mountains and forests into two of the largest rivers in the region, the Shoshone River and Wind River, and subsequently into the Bighorn River. The study area has a population of about 100,000 people, and the water resources flowing off the SNF provide a diverse range of WESs important to the economy, and cultural and natural heritage. For example, 26.3 % of employment in the study area is derived from industries relying on and affecting water quality and quantity such as farming and ranching, outfitting and guiding, oil and natural gas extraction, and accommodation and food services (Bureau of Economic Analysis 2010). The study area is also part of the Greater Yellowstone Ecosystem (GYE), which is of national and international importance for many reasons, including it being a premier tourist destination, home to pristine and unique ecosystems, and the nation's first national park.

There are three Native American tribes (Crow, Northern Arapaho, and Eastern Shoshone) currently residing in the study area, who rely on clean water and healthy instream flow not only for many of the same benefits that support non-native communities, but also for sacred ceremonies and the provision of culturally important plants (Armatas 2013). The development of water resources for the cattle and agricultural industries is entwined with the pioneering history of the study area dating back to the homesteaders of the late 1800s, which is a significant part of the region's identity (Bonner 2003, Bonner 2005).

Assessing vulnerability of stakeholders with Q-methodology

To improve the chance that vulnerability assessments will actually inform policy- and decision-making, stakeholder involvement and interaction with scientists throughout all stages of assessments are needed to define and understand the spatial and temporal scales of the study area, highlight desired states of ecosystem service provision, and provide place-based information, such as that related to specific vulnerabilities and potential adaptation strategies (Schröter et al. 2005; Eakin and Luers 2006; Füssel and Klein 2006; Smit and Wandel 2006; Carter et al. 2007; Mastrandrea et al. 2010). Collecting process information from stakeholders can highlight multiple and disparate perceptions of vulnerability, which have been shown to influence the willingness to implement adaptation strategies (Grothmann and Patt 2005; Krömker et al. 2008), is important for providing context regarding stakeholder conflicts that stem from different interests (Gallopín et al. 2001), and may impact support of adaptation strategies proposed by land management agencies acting as stewards of public land (Fischer et al. 2013).

Considering that integrated vulnerability assessments of complex social–ecological systems often require many years of coordination and multidisciplinary approaches combining both bottom-up, community-centric narratives regarding conditions of vulnerability, and broad top-down quantitative assessment and modeling (Downing 2004; Schröter et al. 2005; Carpenter et al. 2009; Salter et al. 2010), it is unlikely that any single method will be sufficient for completing such an assessment. However, Q-methodology is a well-rounded approach for gathering process information, which positions the researcher to pursue a more extensive integrated assessment. Q-methodology involves a rank-ordering exercise, known as the Q-sort, which obtains "insight into the values and preferences held by the public" about a topic of interest (Steelman and Maguire 1999, p. 362). The method does not aim to measure the prevalence of any viewpoint, but instead to understand, in a nuanced fashion, the full range of existing viewpoints. A thorough discussion of Q-methodology can be found in Brown (1980) and Watts and Stenner (2012). Here, we present a brief description of the method and how it was applied to understand social vulnerability in northwest Wyoming, USA.

Developing the Q-set

The first step in a Q-methodology study is to develop the Q-set, which is a collection of items or statements related to the research topic that will be rank ordered by participants. This generally involves literature review, interviews, and focus groups. However, the approach chosen is less important than ensuring that the final Q-set represents the full range of sentiments regarding the topic of interest (Watts and Stenner 2012).

The goal for the Q-set in this study was to include the full range of WESs being derived from the SNF. This was achieved primarily through review of ecosystem services literature, study area-specific water and climate change literature, and two focus groups with a broad range of stakeholders. The 18 focus group attendees, listed in Table 1, were identified by an internet search and phone conversations with federal, state, and local water resource managers, and citizens connected to water for professional and personal reasons (e.g., farmers and water recreation enthusiasts). The focus groups did not include Native American tribal members; however, informal meetings, both one-on-one and in a group setting, provided tribal members the opportunity to comment on the Q-set.

Following a broad discussion on the ecosystem services concept, each focus group participant was asked to identify WESs derived within the study area, and then, the group as a whole worked together to define each WES. To the greatest extent possible, all WESs were included in the Q-set, regardless of perceived importance a priori, to provide the greatest opportunity for a broad range of stakeholders to express their interests. Furthermore, the definitions for the WESs in the Q-set often included exact wording offered by participants based upon the rationale that such wording would be understandable to participants from the study area. Pilot testing with the general public was used to finalize the Q-set for the case study.

Developing the P-set

The second step requires the recruitment of participants to complete the Q-sort, who are collectively referred to as the P-set. The P-set is obtained by strategic sampling, not random sampling of a large number of participants, to ensure "comprehensiveness and diversity, rather than representativeness or quantity" (Eden et al. 2005, p. 417). This is because Q-methodology is "intended to identify subjectivities that exist, not to determine how those subjectivities are distributed across a population" (Brown et al.

Table 1 Focus group attendees for Q-set development

Cody, Wyoming	Riverton, Wyoming
Whitewater Rafting Outfitters	Department of Environmental Quality
Greater Yellowstone Coalition	Wyoming Game and Fish
Fly Fishing Outfitter	Cooperative Extension Services
BLM Recreation	Fish and Wildlife Service
Forest Service Archeology	Wyoming Outdoor Council
Forest Service Hydrology	Local Conservation District
State Engineers Office	Local Rancher
Irrigation District Management	Local Farmer and Livestock Feeder
Guest Ranch Owner	
Trout Unlimited	

1999, p. 602). Stainton Rogers (1995) asserted that a P-set of 40–60 participants is most effective in capturing a diverse range of viewpoints. Indeed, fewer than 60 participants are commonly recruited in Q-studies (e.g., Vugteveen et al. 2010; Gruber 2011; Ray 2011). Development of the theoretical target P-set is facilitated by the dimensional sampling approach developed by Arnold (1970), which encourages explicit delineation of the population being sampled into combinations of the various categories, or ‘dimensions’, that define an overarching typology.

To uncover diverse perceptions about stakeholder vulnerability in northwest Wyoming, a typology of people interested in WESs was developed to account for both area of interest (e.g., fishing, agriculture, and environmental conservation) and alignment within the organizational structure of management and policy-making in the United States (e.g., private sector, local government, state government, and tribal government). The categories of this typology were defined through extensive research of the study area, two meetings with local Forest Service personnel, discussions during the two focus groups conducted to define the Q-set, and snowball sampling employed during the exit interview with members of the P-set. Snowball sampling, or chain referral method, builds a sample based on referrals from people who know of others who may be interested or knowledgeable about the research topic (Biernacki and Waldorf 1981). For this study, snowball sampling was used as a secondary means to enrich the sample, because the researchers felt that a topic as broad and salient as water was likely to be of interest to groups or individuals not uncovered by literature review and discussions with land management personnel.

Q-sorting exercise and exit interview

Step three requires the participants (P-set) to rank order the statements from the Q-set in an exercise known as the Q-sort. This exercise requires the participants to decide, from their perspective, that which is important and, conversely, that which is not. The participants are given a deck of shuffled cards (each card contains one statement from the Q-set) to be placed onto the Q-board, which provides the framework for the Q-sorting process. Q-boards typically (but not always) require participants to distribute the cards in a manner similar to a normal distribution, as illustrated in Fig. 2. Brown (1980) described the rationale for alternative Q-board designs. The participant is instructed by the researcher to sort the cards onto the Q-board in order of importance, with each column denoting a different level of importance. The number of rows dictates how many cards from the Q-set belong in each column.

After the Q-sort is complete, the researcher normally conducts an exit interview, in which the participant is asked to discuss the reasoning for ranking the statements in their unique way (Brown 1980). In addition to factor analysis, the interviews will help to give the Q-sorts meaning. The exit interview is also an appropriate time to collect demographic information, which can assist the researcher in understanding if the P-set represents a diverse range of sentiments.

In the case study, each member of the P-set attended a one-on-one meeting with the lead author at a convenient location within the study area, which included residences, places of work, and public meeting places. During those meetings, the participant completed the Q-sorting exercise, where they sorted the WESs on the Q-board illustrated in Fig. 2, and an exit interview. During the exit interview, participants provided demographic information and engaged in a short discussion regarding drivers of change considered to be potentially influential on the flow of their two ‘most important’ WESs. Specifically, each participant was asked, “what factors, influences, or things do you see as potentially affecting your ability to receive your most important two WESs in the future, either positively or negatively?”

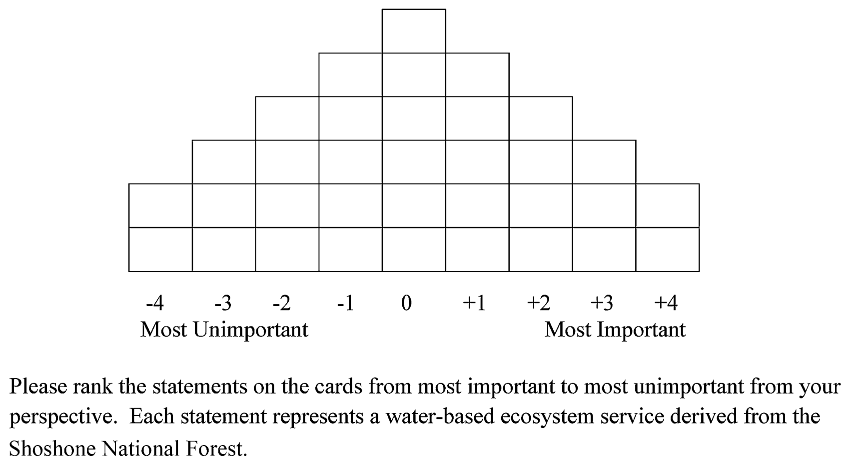

Fig. 2 Q-board and instructions given to the participant for the Q-sorting exercise in the case study

Data analysis and interpretation

Steps four and five in a Q-methodology study are data analysis and interpretation. Factor analysis, including varimax or judgmental factor rotation, is employed to analyze the Q-sort data (Brown 1980). Results are represented by factor arrays, which are typified Q-sorts defined by all of the participants who load onto a particular factor. Each factor array represents a generalized viewpoint or perspective with regard to the topic of investigation. The factor arrays are defined by purely loading Q-sorts, which are those that load significantly onto one factor only. A Q-sort can also be confounded (loads significantly onto more than one factor) or null (does not significantly load onto any factor). Confounded Q-sorts are typically not used in the construction of the factor arrays, because they are a reflection of at least two factors, which can increase the correlation between factors and make the resulting factor arrays less distinct. Nevertheless, confounded Q-sorts can still be explained in terms of the resulting factor arrays onto which they significantly load. Those Q-sorts that are null are considered to be idiosyncratic viewpoints, which are not explained by any of the resulting factor arrays and do not contribute to the interpretation of the factor arrays. These are outlier perspectives, and do not suggest another common viewpoint (otherwise factor analysis would have revealed it).

Factor interpretation typically involves a write-up exercise, which conveys the meaning of each factor array with the aid of information gathered during the exit interview. Each factor interpretation includes relevant quotes and demographic data from participants that help to define each viewpoint. The factor arrays yielded in this step identify those items for a particular viewpoint that are important (right side of the Q-board), unimportant (left side of the Q-board), and lacking salience (middle of the Q-board). By comparing factor arrays of each perspective, it is also possible to identify those items about which there is consensus, contention, and ambivalence among the perspectives.

Centroid factor analysis and varimax rotation were applied to the case study Q-sort data, and interpreted using qualitative data collected during the exit interviews.

Results of case study

The Q-set developed for this study is reported in Table 2, and the WESs have been categorized as regulating, production or cultural ecosystem services, as defined in the table. Obvious WESs, such as water for household use, were included with more obscure benefits, such as nutrient cycling and sediment transport.

Purposeful sampling resulted in a P-set of 96 stakeholders who were not participants in the two focus groups or pilot testers of the Q-set. Table 3 reports the composition of the P-set by sector and interest group. The size of the P-set is considered large for a Q-methodology study.

In accordance with good practice in Q-methodology, the factor solution chosen was based on both statistically-objective criteria (e.g., the Scree test, Humphrey's Rule, the significant loading test, and the eigenvalue test) and theoretical significance (e.g., researcher intuition, and social and political context) (Brown 1980; Watts and Stenner 2012). Factor analysis of the 96 Q-sorts resulted in a three-factor solution with four distinct viewpoints about the importance of WESs and the drivers of change that are perceived to threaten those important ecosystem services. The three factor solution explained 48 % of the study variance, which is considered to be a sound solution by

Table 2 Q-set of water-based ecosystem services

Ecosystem service title	Ecosystem service definition
Regulating services	"Regulation services result from the capacity of ecosystems to regulate climate, hydrological and bio-chemical cycles, earth surface processes, and a variety of biological processes" (Hein et al. 2006, p. 212)
1. Water quality	The water in and flowing from the SNF is purified and filtered by natural systems like beaver ponds and wetlands resulting in clean water
2. Instream flow	The water from the SNF that is not drawn from the river can help to create and maintain healthy aquatic habitats. For example, a certain amount of water in the stream can maintain channel form and function, and regulate water temperature
3. Conservation of keystone (critical) species	The water within the study area helps to support important plant and wildlife species. For example, the whitebark pine, beaver, and cutthroat trout are considered keystone species of the Greater Yellowstone Ecosystem (GYE), which means they are important for the conservation of a host of other species
4. Conservation of rare plant species	Wetlands within the study area support a number of rare plant species. The rare plants may have some use that is unknown to humans at this time, but they could be beneficial in the future
5. Biodiversity conservation	Aquatic and riparian areas fed by the SNF provide habitat for a diversity of species, and genetic variation within species. Species diversity may help maintain ecosystem structure, processes and functions
6. Gradual discharge of stored water	Water released into streams and rivers is naturally regulated by glaciers, wetlands, riparian areas, and aquifers, which provides a reliable flow of water throughout the year, even during the warmest summer months
7. Natural flood control	The storage of SNF water in glaciers, wetlands, riparian areas, and aquifers provides natural flood control, which avoids flooding damage costs
8. Glacier-based services	The glaciers in the SNF are of the largest concentration in the lower 48 states, and they provide unique services like stream-water temperature regulation, summertime skiing, and glacier sightseeing
9. Nutrient cycling and sediment transport	The water flowing from the SNF helps to cycle nutrients and transport sediment. Nutrients cycled throughout the natural system helps to maintain healthy and diverse aquatic habitats. The transport of sediment helps to create floodplains and riparian areas
Production Services	"Production services reflect goods and services produced in the ecosystem" (Hein et al. 2006, p. 212)
10. Household/Municipal water	Water in the study area, both surface water and groundwater, can be used for drinking, washing, and other in-house use
11. Hydropower	Water provided by the SNF can be used to generate hydropower
12. Commercial irrigation	The water in the study area, both surface water and groundwater, can be used to irrigate commercial crops, which could include hay, sugar beets, corn, grain, barley, and beans. These crops could be sold on the market and/or used to support ranching activities
13. Personal irrigation	The water in the study area, both surface water and groundwater, can be used to fill private ponds, and irrigate gardens and lawns
14. Water for stock	Water provided by the SNF can be used for the watering of stock
15. Manufacturing and industrial	The water in the study area, both surface water and groundwater, can be used for manufacturing and industrial purposes
16. Oil and natural gas extraction, and mining	The water in the study area, both surface water and groundwater, can be used for the extraction of natural gas and oil, and to a lesser extent, in the mining of coal, bentonite, uranium and gypsum. Water is also used in these industries for dust control on roads
17. Fighting forest fires	Water provided by the SNF can be used for the fighting of forest fires
18. Supporting of commercial land-based recreation	Water provided by the SNF facilitates land-based recreational activities. For example, the watering of golf courses, the water used to make snow for the Sleeping Giant Ski Area, and the water used for amusement parks
Cultural Services	"Cultural services relate to the benefits people obtain from ecosystem through recreation, cognitive development, relaxation, and spiritual reflection" (Hein et al. 2006, p. 212)
19. River-based fishing	The rivers throughout the study area can be used for fishing, both for sport and the harvesting of fish for personal consumption
20. Lake/Reservoir fishing	The lakes and reservoirs in the study area provide the opportunity for fishing, both for sport and the harvesting of fish for personal consumption
21. Lake, reservoir, and river-based hunting	The lakes, reservoirs, and rivers throughout the study area provide opportunities for hunting waterfowl from the water in a boat

Table 2 continued

Ecosystem service title	Ecosystem service definition
22. Land-based hunting	The water resources in the study area provide habitat for game and, as a result, watercourses and wetlands can be used for land-based hunting
23. River recreation	The rivers flowing in and out of the SNF can be used for both whitewater and scenic recreational activities. Some include: rafting, kayaking/canoeing, stand-up paddle boarding, tubing, body boarding, surfing, river-access hiking, and bird watching
24. Lake/reservoir recreation	The lakes and reservoirs in the study area provide opportunities for recreational activities. Some include: water skiing, wakeboarding, kneeboarding, skurfing, tubing, sailing, motorboating, parasailing, canoeing, kayaking, and kiteboarding
25. Commercial water-based recreation	Outfitted whitewater rafting trips and guided-fishing trips are two examples of commercial water-based recreation sold on the market. Both opportunities are provided by the water resources in the study area
26. Motorized ice- and snow-based recreation	The ice and snow within the study area can be used for motorized winter recreational activities like snowmobiling
27. Non-motorized ice and snow based recreation	The ice and snow within the study area can be used for a number of non-motorized winter recreational activities. Some include: skiing, snowboarding, ice climbing, winter camping, and snowshoeing
28. Recreation/Leisure activities done near water	For example, the experience of wildlife viewing and hiking could be done in close proximity to a water resource within the study area. Additionally, reflective recreational activities like introspective thought may be done near water
29. Physically and mentally challenging recreation	The water environments within the study area can provide opportunities for physically and mentally challenging recreational opportunities
30. Education, management and science	The aquatic habitats and water-based ecosystem processes within the study area can be studied with the goal of improving both management and objective knowledge of natural and social sciences, which include biology, botany, hydrology, and history
31. Native American cultural and spiritual values	The water resources in the study area have special meaning to Native Americans, and can be used for cultural, spiritual, religious and ceremonial purposes
32. Non-Native American cultural and spiritual values	The water resources in the study area have special meaning to Non-Native Americans, and can be used for cultural, spiritual, religious and ceremonial purposes
33. Preserving livelihoods, lifestyles, and landscapes	The water flowing from the SNF is used to support healthy agricultural communities and large working farms and ranches
34. Inspirational and aesthetic values	The rivers and lakes in an around the SNF can provide inspiration and enjoyment. For example, a scenic water vista can provide the motivation for an artist's work, and the beauty, smell, and sound of water can provide enjoyment

Kline (1994). The factor solution provided four perspectives for interpretation because of a bipolar third factor. That is, a factor defined by both positive and negative loading Q-sorts or viewpoints.

The factor arrays for the four perspectives are presented in Fig. 3, and the numbers within the factor arrays correspond with the numbering of ecosystem services in Table 2. The perspectives were named environmental, agricultural, Native American, and recreation, because of the high level of importance assigned to particular contrasting ecosystem services by the respondents who helped to define each perspective. Of the 96 total participants, 74 loaded purely onto one of the four viewpoints (35 on the environmental, 26 on the agricultural, 8 on the Native American, and 5 on the recreation), 8 were confounded, and 14 were null cases.

In the description of each perspective that follows, numbers in parentheses that range from −4 to +4 represent the level of relative importance from the Q-board that particular perspective assigned to the WES being discussed. Several quotes from exit interviews by participants who loaded onto particular perspectives are provided to highlight detailed contextual information collected in a Q-methodology study.

Environmental perspective

Interviewees who aligned with the environmental perspective, including a conservation-based nonprofit worker, several commercial recreation outfitters and guides, an outdoor educator, and an ecologist, placed a high level of importance on WESs that regulate and support a healthy environment, as is evident by the eight regulating services populating the right side of factor array A. Water quality (+4) is paramount for the environmental perspective, because it maintains a healthy river environment, which supports river-based fishing (+2), the conservation of keystone species (+3), and biodiversity conservation (+4).

Table 3 P-set of interest groups surveyed on importance of water-based ecosystem services

Sector (number surveyed within sector)		Sector (number surveyed within sector)	
Interests/groups (number surveyed)		Interests/groups (number surveyed)	
Private sector	(32)	Tribal Governments	(11)
Fishing outfitters and guides	(3)	Business council	(1)
Hunting outfitters and guides	(1)	Environmental Quality Commission	(2)
Whitewater raft companies	(4)	Fish and Game	(3)
Guest ranches	(1)	Engineers Office	(1)
Farmers	(5)	Water and Wastewater	(2)
Ranchers	(2)	Water Quality	(1)
Winter recreation enthusiasts	(3)	Employment Rights Office	(1)
Summer recreation enthusiasts	(2)	Local Government	(13)
Golf course/ski area employees	(2)	County Commissioners	(3)
Mining/gas/oil industry	(1)	Town Mayors	(1)
Average interested citizen	(5)	Conservation Districts	(3)
Manufacturing/industrial use	(1)	Weed and Pest Districts	(2)
Outdoor education	(2)	County Planners	(1)
Non-Governmental Organizations	(11)	Water and Sewer Districts	(1)
		Irrigation Districts	(1)
Wyoming Outdoor Council	(2)	Wyoming Farm Service Agency	(1)
Wyoming Stock Growers Association	(1)	Federal Government*	(18)
Wyoming Wilderness Association	(1)	Recreation	(2)
Greater Yellowstone Coalition	(1)	Climate Change Research	(1)
Trout unlimited	(1)	Hydrology	(2)
Wyoming heritage	(1)	Archeology	(2)
		Silviculture	(1)
OHV Alliance	(1)	Planning	(1)
Wyoming State Snowmobile Association	(1)	Hydropower	(1)
Biodiversity Conservation Alliance	(1)	Plant Ecology	(1)
Dude Ranchers Association	(1)	Soils Science	(1)
		Natural Resource Extraction	(2)
State Government	(11)	Natural Resource Specialist	(3)
State Engineers Office	(1)	Biology	(1)
University of Wyoming	(2)		
Cooperative Extension Services	(2)	Total Surveyed	(96)
Game and Fish Department	(1)		
Wyoming Water Development Commission	(2)		
Department of Environmental Quality	(1)		
Department of Agriculture	(1)		
State Parks	(1)		

Workers from the following federal agencies completed Q-sorts, but to protect confidentiality the interests represented within the federal agencies will not be attributed to a specific agency: Bureau of Land Management, Forest Service, National Park Service, US. Fish and Wildlife Service, Bureau of Reclamtion, Bureau of Indian Affairs, Natural Resources Conservation Services, and Army Corps of Engineers

Participants 14 and 15 stressed that water quality maintains the Yellowstone cutthroat trout, which is critical for maintaining the study area's reputation as a world class fishing destination and the stability of its aquatic ecosystems. Instream flow (+3) is crucial for the health of the river and its ability to benefit humans: "We lose some of these streams that run dry, and then you lose that water quality. Water quality is threatened and then the biological diversity is threatened, and even the human use of that stream is threatened" (Participant 50).

The WESs that are viewed as unimportant by this perspective are the production services, which populate the left side of the factor array, and are often perceived as threatening to the important regulating WESs. For

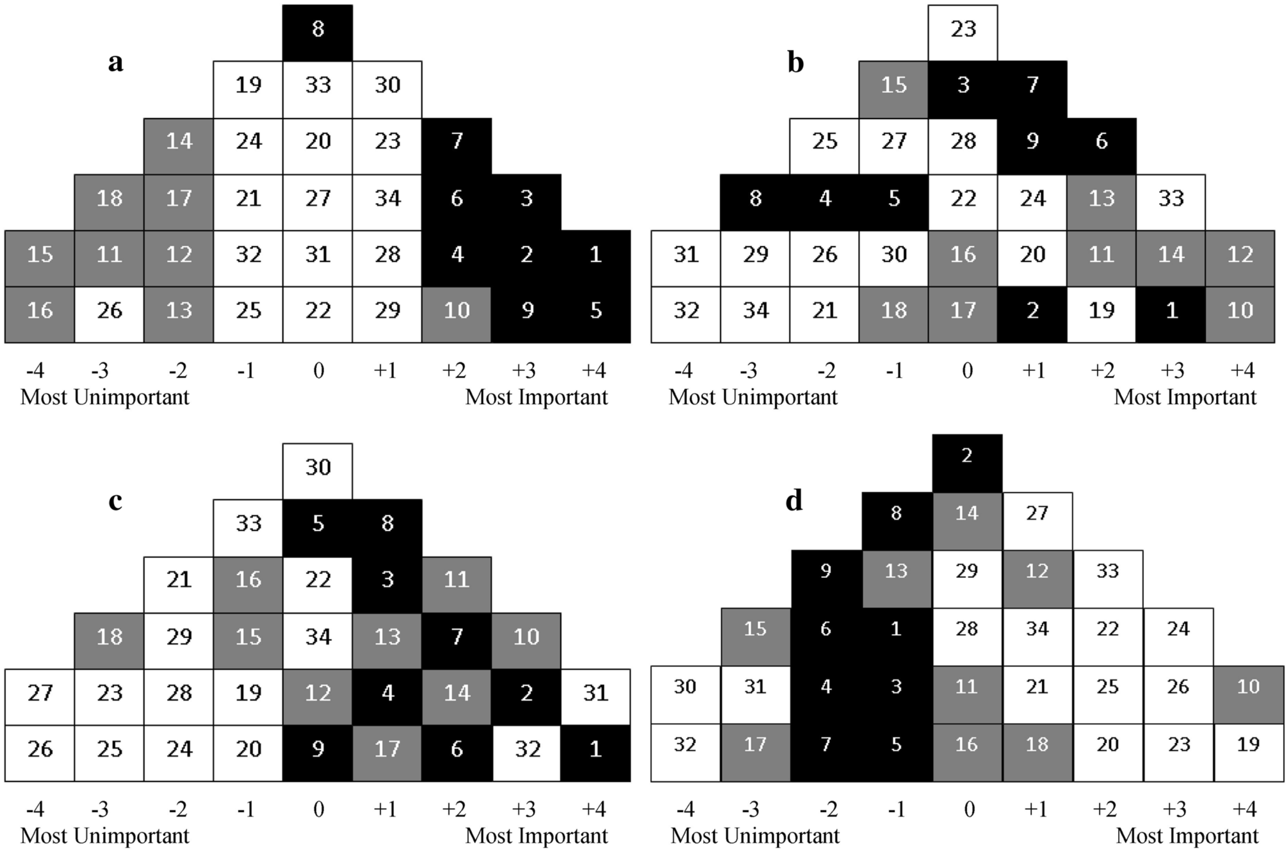

Fig. 3 Factor arrays illustrating the relative importance of water-based ecosystem services to participants who hold the: **a** environmental perspective; **b** agricultural perspective; **c** Native American perspective and **d** recreation perspective

example, agricultural WESs such as commercial irrigation (−2) and water for stock (−2) are seen as threatening. Participant 51 asserted, "the thing we worry about most for in-stream flow would be the development of it for commercial or agricultural interests, potentially residential". Participant 13 saw agriculture as a threat to fishing, "I see us having really bad in-stream flows, (which are) inconsistent from year to year, very poorly managed, short-sighted and made for irrigation and agricultural goods and services, and that is it". Oil and natural gas extraction, and mining (−4) provide economic stimulus to the study area, but these activities are considered threats to regulating ecosystem services such as nutrient cycling and sediment transport (+3) and biodiversity conservation (+4). Participant 93 stated, "if we have increased oil and gas production on the [SNF], I think there is possibility with extracted water and effluent holding ponds [and] the entire extraction process has the ability to disrupt appropriate cycling sediment transport [and wildlife] habitats". Hydropower (−3) is also unimportant to the environmental perspective, because its generation can have negative effects on in stream flow and riverine ecosystems.

Other drivers that were of concern to the environmental perspective were the potential impact of a changing climate, particularly as it relates to biodiversity conservation and the health of native cutthroat trout populations and the ability of the land to store water with the loss of wetlands due to warm temperatures. The potential impact of climate change, land management, and other drivers, such as the provision of WESs such as agriculture were perceived to be influenced by spatial distribution. Participant 13 suggested, "the second it hits ranch land the water quality starts to fall apart", and Participant 27 noted, "almost all the water that comes [out of the SNF] comes out of wilderness, so the Forest Service cannot affect it positively or negatively, which I think is very good".

In vulnerability terms, those who align with this perspective are: (1) threatened by extractive water use and climate change; (2) highly sensitive to a loss in regulating ecosystem services (i.e., those that support functioning ecosystems); (3) limited in terms of adaptive capacity because of priority given to extractive water uses outside the SNF and the hands-off management dictated by wilderness designation; and (4) exposed in a relatively small amount in areas that are protected, such as the SNF and its associated designated wilderness, with higher exposure outside the SNF where the majority of extractive water use is taking place.

Agricultural perspective

The agricultural perspective, defined by participants including farmers and ranchers, county commissioners, randomly selected citizens, and an economist, who assigned high importance to the four ecosystem services that are related to agriculture [commercial irrigation (+4); personal irrigation (+2); water for stock (+3); and preserving lifestyles, livelihoods, and landscapes (+3)], and the regulating services that support agriculture [water quality (+3) and gradual discharge of stored water (+2)]. According to this perspective, agriculture supports more than just the farming and ranching community, since without water for stock (+3), "people would be forced to look outside the area or region for stock, so it would drive [beef] prices up" (Participant 10). Those who subscribe to the agricultural perspective rely on water quality (+3) and quantity to maintain healthy agricultural communities, which preserve livelihoods, lifestyles, and landscapes (+3). Participant 45 noted that if there isn't enough water, "then those of us that depend on irrigation to produce crops and water for livestock would have to reduce our income basically, because that is how most of us make our income". The sensitivity of this perspective to loss in water quality and quantity is evident in a comment by Participant 44, "the quality of water and the quantity that has been supplied off the forest, and historically livelihoods have been developed. Agricultural communities, everything we do, the reason we live where we do is because of the water running off the mountains".

Several ecosystem services that are considered to be unimportant by the agricultural perspective are those that compete with agriculture. This perception, as illustrated in the factor array, was confirmed by Participant 31, who commented, "increased pressure from conservation groups, fishing, in-stream flow and anything like that would influence the ability to use it for commercial irrigation". However, water for agricultural use is considered to be relatively insensitive to a variety of drivers. The system of dams and reservoirs within the study area assuages many of the concerns about water availability and potential impacts of climate change, which may be why glacier-based services (−3) are unimportant despite their support of late-season water flow in the study area. Some participants anticipated a benefit from warmer temperatures predicted with climate change. Participant 20 noted about warmer temperatures, "I get to grow more in the garden, more fruit trees. It is actually benefitting me personally, because I can grow more stuff". Regarding the potential loss of water availability to competing uses, such as increased residential demand, Participant 20 acknowledged the threat. but added a caveat that senior water rights are a mitigating factor. "Trying to maintain the water use for irrigation is going to impacted not only by the number of individuals pulling water for small yards and drinking water, [which] takes away a lot from the agricultural water source. Luckily, in Wyoming we do have the senior water rights that go with the land, but I can see challenges coming up if the population of this area grows much more, and or the downstream users all the way to the Gulf of Mississippi, because that is where our water ends up" (Participant 20).

In vulnerability terms, the stakeholders that align with the agricultural perspective are: (1) threatened by competing uses for residential and environmental purposes; (2) highly sensitive to a change in provision of commercial irrigation water; (3) able to adapt to potential issues such as climate change because of water storage that is primarily operated for agricultural purposes; and (4) minimally exposed to the aforementioned threats as a result of well-defined property rights to water that limit the threat posed by conservation groups and residential development.

Native American perspective

The Native American perspective, defined by members of the Eastern Shoshone and Crow tribes working mostly for tribal government agencies, was one of two distinct bipolar viewpoints that loaded onto the third factor. Native American cultural and spiritual values (+4) and water quality (+4) are most important, because both WESs are integral in the lives of this perspective and well-being is sensitive to changes in the provision of these benefits. Participant 77 explained, "Our way of governing, our way of teaching, our love for each other came from that River corridor…that is our stories, we come out of the water". Instream flow (+3) is also important for Native American cultural and spiritual values. Participant 57 asserted that, "if they are going to lower the water, we have less water for the plants and, so, that causes a shortness of growth for our natural plants that we use culturally".

In general, recreation is unimportant to the Native American perspective, and as recreational opportunities continue to increase, the threat of natural resource degradation and its subsequent impact on cultural sites is perceived to increase. Participant 84 explained, "if the Bighorn Recreation Area is developed, yeah it is going to affect our cultural sites in that area…the [proposed] 'transpark road' goes right through the heart of our prime hunting grounds." Those who align with the Native American perspective regard provisioning services such as hydropower (+2) and water for stock (+2) to be important because, in the case of the Crow Indians, a recent agreement with the United States government (Water Settlement Act of 2010) provided funding for the development of agriculture and hydropower, which can create much needed economic opportunities on the reservation.

In addition to the threat of increased recreation opportunities on the provision of Native American cultural and spiritual values, are the threats of pollution and changes in water temperature. Participant 85 explained the connection between water quality and an important cultural ceremony known as the Sacred Sweat: "It has been with the Crow Indians for a long time, the so called 'Sweat', and it is very important. When you have no place to sweat or dip [in the river] after that, you do not want to dip in the river so that affects that, you know, the pollution that goes into that river". According to Participant 47, one source of water pollution is acid rain as a result of air pollution from oil and natural gas development taking place hundreds of miles away. The fact that the oil and gas development is happening in another jurisdiction suggests that adaptive capacity is limited in this case.

In terms of vulnerability, those who align with the Native American perspective are: (1) threatened by pollution, loss of instream flow, and increased recreation opportunities in particular areas of importance; (2) highly sensitive to changes in the provision of Native American cultural and spiritual values and water quality; (3) limited in their ability to adapt to stressors such as pollution and loss of instream flow; and (4) exposed to loss of water quality and quantity as a result of being downwind from air pollution sources and having limited water rights relative to extractive stream uses such as agriculture.

Recreation perspective

The recreation perspective is the second distinct viewpoint that loaded onto the third factor. This perspective, defined by participants including a local business owner, hunting guide, and motorized recreation advocate, regards almost all types of water-based recreation as important, which is reflected by 10 out of 12 recreation ecosystem services being ranked as positively important. Conversely, the recreation perspective sees regulating services as unimportant, which is reflected by all but one of them falling on the negative side of the Q-board. Particular recreational ecosystem services, such as motorized ice and snow-based recreation (+3) and lake/reservoir recreation (+3) are viewed as a boon to the economy by the recreation perspective, because of the expenses (e.g., fuel) associated with the machines. Also, motorized recreational uses are seen as a way to generate money for federal land management agencies, because they are required to pay a fee to register their vehicles for use on federal land. At the forest level, those who adopt the recreation perspective support multiple uses of resources and less restrictive management. Participant 41 declared, "the more management you have the more politics that you have, so, what happens is the Forest Service is going broke…but, if you don't have mining or logging, you don't have funding for recreation or anything".

The recreation perspective assigned a high level of unimportance to education, management, and science (−4) because there is a perception that increased management and scientific inquiry will threaten recreation opportunities on the SNF. Participant 41 remarked, "We can't get the trails generated. A lot of these trails were existing 20 or 30 years ago, and then they closed them due to the roadless acts or grizzly reasons or whatever, and once it gets taken away it doesn't ever come back, even if the circumstances are changed, we can't get them back". Furthermore, there is a feeling that rigid management and misinformation damage the opportunity for increased recreation. Participant 40 stated, "it is a no net gain, if you shut a trail down, it is gone, you are not going to get it back. It [takes] an act of congress to get it back" and, regarding the lack of logic in management, "snowmobiles, we stake our trail on top of snow! When the snow is gone, you don't even know we have been there". Participant 56 added that management closes snowmobiling trails for reasons which are "not totally logical".

In terms of vulnerability, those who subscribe to the recreation perspective are: (1) threatened by management approaches that prioritize other WESs over recreation; (2) sensitive to losses in recreation, particularly motorized winter recreation (3) lacking adaptive capacity without any ability to influence management approaches; and (4) exposed to management of the SNF which is perceived to favor the environment over recreation.

Discussion of Q-methodology results in the context of vulnerability assessment

With reference to the case study, this section discusses benefits and limitations of Q-methodology for improving understanding of the vulnerability of social–ecological systems. Although the process of Q-methodology includes procedures integral to other research methods, such as literature review, focus groups, and one-on-one qualitative interviews, the combination of these procedures with unique aspects of Q-methodology, such as the rank-ordering exercise and statistical analysis of the Q-sorts, yields a well-rounded and thorough understanding of stakeholder perspectives of vulnerability. Specifically, Q-methodology results in:

- identification of multiple stakeholder perceptions about the importance of variables of concern and their vulnerability to drivers of change;
- an understanding of where perceived vulnerability and actual vulnerability may not align;
- a foundation for performing subsequent steps of an integrated vulnerability assessment such as the top-down simulation modeling of values, qualities, and quantities of ecosystem services in response to drivers;
- a firm understanding of a study area defined with direct input from stakeholders; and
- a clear and captivating tool for communicating the aspects of vulnerability to a broad range of stakeholders.

Multiple stakeholder perspectives of vulnerability

The case study presented identified four perspectives via factor arrays and exit interviews, where the former highlighted ecosystem services about which there is contention, consensus, and ambivalence, and the latter provided additional qualitative data for supporting the interpretation of the factor arrays. These unique perspectives contribute to an improved understanding of vulnerability from the stakeholders' perspectives, with information about desired WESs, and distributional tradeoffs, inequities, and drivers threatening the provision of desired WESs. For example, the factor arrays highlighted the polarizing attitudes toward Native American cultural and spiritual values, motorized ice and snow-based recreation, commercial irrigation, and hydropower. The Native American perspective considered increased recreation opportunities such as motorized recreation to be a threat to their most important WES, Native American cultural and spiritual values. On the other hand, the recreation perspective had a polar opposite view, which highlights a tradeoff that managers and policymakers may want to consider when making decisions. The environmental perspective and the agricultural perspective see biodiversity conservation as a contentious WES. From the environmental perspective, management of water that favors agricultural use amounted to an inequity that harms environmental health and fishing. For the agricultural perspective, however, the use of water for agriculture amounts more to a distributional tradeoff, which is justified by long-standing water rights. Although there are no WESs in this case study that were viewed with ambivalence by all perspectives, the middle area of the Q-board can highlight those ecosystem services that are not as relevant to the perspectives.

A community-centered approach that focuses on multiple drivers is important for maintaining human well-being and identifying potential adaptation approaches (Bennett et al. 2016). The recently completed Forest Plan on the SNF highlights circumstances where the results from this study could be potentially beneficial. For example, the plan explicitly discusses the need to mitigate impacts to Native American cultural resources that may result from "management activities" (USDA 2015: 108); however, the plan fails to mention specific activities that may result in impacts. This study suggests that activities reducing instream flow and recreation activities, particularly those that require road development, are of concern to the Native American perspective.

Difference between perceived vulnerability and actual vulnerability

Although vulnerability assessments should aim to include a 'multiplicity of legitimate perspectives' without focusing on whether such perspectives are correct or true (Gallopín et al. 2001), it can be helpful to understand when stakeholder perceptions about vulnerability are likely misguided, because these areas of misunderstanding can inform extension and education programs. For example, respondents expressing the agricultural perspective were not concerned about the potential impact of climate change on agriculture because of the water storage capacity in the study area. However, if particular impacts of climate change come to fruition (e.g., earlier spring runoff), then the adaptive capacity may be more limited than perceived.

Differences between perceived vulnerability and actual vulnerability may also result from differences in perceived relevant temporal scales. Continuing the climate change example, several stakeholders who valued agricultural services (i.e., water for stock; personal irrigation; commercial irrigation; and preserving livelihoods, lifestyles, and landscapes) were more concerned about restrictive water management in the short run (e.g., increase of instream flow rights) than climate change. The potential impacts of climate change were commonly dismissed because of the perception that those impacts would not happen in their lifetime. This indicates that the timeline for managers and scientists with regard to the stressor of climate change is not relevant to some stakeholders, which could be a source of contention if water policy and management shifts away from the status quo.

Platform for future phases of integrated vulnerability assessments

The Q-methodology approach presented here methodically refined the focus of a vulnerability assessment from a broad range of individual stakeholders, each with their own opinions about important ecosystem services and drivers of change, to a manageable number of statistically- derived perspectives. This is critical for ensuring that the modeling steps in an integrated vulnerability assessment are tractable. With Q-methodology having identified WESs about which there is consensus, contention, and ambivalence, there is a basis for economists to select particular WESs for socioeconomic valuation, a necessary step in holistic vulnerability assessment of social–ecological systems. This will facilitate evaluation of alternative simulated future scenarios in terms of overall performance, as well as distributional impacts on particular perspectives revealed by Q-methodology. Armatas et al. (2014) described the benefits of Q-methodology for informing valuation of non-market ecosystem services, including a structured process for pre-survey development required by stated preference approaches.

Defining and understanding the study area

Definition of the Q-set and P-set through literature review, focus group meetings, and pilot tests result in a study area definition based on direct input from stakeholders. In this case study, an appropriate spatial scale for the study area emerged after definition of the Q-set and P-set. While interacting with stakeholders, for example, ecosystem services related to agriculture, such as commercial irrigation and water for stock (the Q-set), were commonly discussed, and it became clear that such benefits were being derived by people (P-set) mostly outside the SNF. Therefore, even though the boundaries of the SNF limit the impact that forest managers can have on sustaining ecosystem services, a landscape approach was necessary, because WESs that originate in the SNF have far reaching benefits.

The focus groups resulted in a nuanced understanding of WESs being reaped in the study area, which ensured that a broad range of variables of concern were included in the analysis. For example, literature discussed the importance of agriculture for the local economy, but focus groups with residents revealed that the agricultural community is considered by non-farmers and ranchers as both a layer of protection against further residential development and a significant part of the region's identity. This knowledge of the study area resulted in the definition and inclusion of the locally important ecosystem service, 'preserving livelihoods, lifestyles and landscapes' within the Q-set.

Communicating vulnerability

Finally, an important aspect of vulnerability assessment is effective communication of potential vulnerabilities to relevant stakeholders (Schröter et al. 2005). The factor arrays produced with this approach provide a visually appealing and understandable vehicle for conveying the alternative perspectives of stakeholders. They can be used to explain why particular indicators of vulnerability were adopted and decrease the chance that particular stakeholders will feel as though their concerns are not being addressed within the assessment. The factor arrays and interpretive write-ups facilitate verification and validation of perspectives regarding the importance of WESs.

The results from this case study were presented to, and well received by, an audience of managers and planners on the SNF. Also, the results were presented to a Native American audience on the Crow Indian Reservation, and through discussions with that audience, it became apparent that additional recreation activities are indeed a threat to sustaining cultural and spiritual use. Both audiences gave positive feedback when viewing and discussing the factor arrays.

Limitations

The application of Q-methodology for understanding social–ecological vulnerability yields several benefits, but there are two limitations worth noting. First, this approach may be more costly, both in terms of time and funding, than other approaches. Second, there is the potential for respondent fatigue, which is inherent in all qualitative approaches that include respondent participation. This application of Q-methodology asks participants to: (1) rank order the Q-set; (2) discuss their unique Q-sort generally; (3) discuss potential drivers threatening important ecosystem services; and (4) complete a brief demographic survey.

To avoid respondent fatigue, the research can prioritize the most important aspects of data collection for understanding vulnerability. In this study, the researcher prioritized 1, 3, and 4. Although these tasks resulted in a great deal of information about each Q-sort generally, there may have been interesting aspects of particular perspectives that were not fully investigated. For example, the recreation perspective ranked water quality as relatively unimportant (−1), but at the same time, river-based fishing was highly important (+4). One possible explanation for this counterintuitive result is that those aligning with this perspective viewed water quality as another reason for management to restrict recreation; however, there may have been a different explanation for this result that was missed as a result of prioritizing the respondent tasks.

Conclusion

The case study on water-based ecosystem services (WESs) flowing from a protected area in Wyoming, USA, highlighted Q-methodology as a useful approach for understanding the perspectives of stakeholders about the importance of WESs and their vulnerability to drivers of change. With stakeholder input, the method gathers process information that highlights multiple perspectives of vulnerability, improves understanding of where perceived vulnerability and actual vulnerability may conflict, helps to define and understand the study area, and provides support for subsequent steps of complex integrated vulnerability assessments. Also, the factor arrays provide an appealing format for communicating vulnerability to stakeholders, managers, and policymakers. Although Q-methodology incorporates several aspects common in other participatory approaches, such as focus groups and one-on-one interviews, the data collection tool that requires participants to make tradeoffs, and the statistical analysis of subjective material make Q-methodology a unique approach that is underrepresented within the vulnerability literature.

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