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An integrated approach to valuation and tradeoff analysis of ecosystem services for national forest decision-making

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ABSTRACT

An integrated approach to understanding ecosystem service values in Wyoming and Montana, USA is presented. The assessment encompasses a major river basin, and includes a synthesis of existing data and research related to the natural system and separate data collection efforts regarding the social and economic importance of ecosystem services. A holistic look at the social-ecological system provides nuanced information about ecosystem service values and tradeoffs for the purpose of public land decision-making.

The initial ecological assessment concluded that water resources were particularly vulnerable, which guided the social and economic assessments. The social assessment applied Q-methodology, ultimately identifying and exploring four archetypes regarding views on the importance of 34 ecosystem services, which were dubbed "environmental", "agricultural", "Native American", and "recreation". The economic assessment applied choice modeling to understand non-market values of ecosystem services (i.e., agricultural community, aquatic biodiversity, river angling, and motorized winter recreation), and latent class analysis provided insight into preference heterogeneity previously indicated in the social assessment. The structured approach can inform natural resource decision-making by including several different perspectives, integrating multiple spatial scales, highlighting particular ecosystem services as relevant within the context of many ecosystem services, and facilitating relations between the public and natural resource stewards.

1. Introduction

The burgeoning ecosystem services concept aligns with contemporary natural resource management and planning in the United States with its broad focus on sustaining the environment and its ability to provide a myriad of benefits. This is a daunting task, which policy guidelines, such as the 2012 Planning Rule for the United States Forest Service (USFS), formalize with an aim to provide for social, economic, and ecological sustainability (U.S. Department of Agriculture Forest Service, 2012). According to the Planning Rule, providing such broad ranging sustainability can be achieved in part by maintaining the flow of services and benefits derived from public forests for both surrounding communities and on-site users.

In pursuit of these goals, both in the context of USFS planning, and natural resource stewardship more generally, management and policy decision-makers increasingly require information about ecosystem services and their tradeoffs that is understandable both to the decision-makers and the public (Deal et al., 2017; Kline et al., 2013). This complicates the decision-making process, as there are a diverse range of ecosystem services that support human well-being (MEA, 2005), and a diverse range of perspectives as to what ecosystem services are valuable (Kenter, 2016). In addition, the 'value' of ecosystem services is expansive. According to de Groot et al. (2002, p. 394), the value of ecosystem services can be categorized into different dimensions related to ecological value, social (or socio-cultural) value, and economic value, which are based on "ecological sustainability", "equity and cultural perceptions", and "efficiency and cost-effectiveness", respectively.

The valuation of ecosystem services, defined broadly herein as the act of 'assigning importance' (or lack thereof), has long been recognized as integral to the decision-making process (Dendoncker et al., 2014;

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Jacobs et al., 2016). However, more recently, there has been increasing recognition that decision-makers should consider diverse stakeholder values and perspectives about what (and why) ecosystem services are important. Specifically, it has been argued that the three value dimensions of ecosystem services (i.e., ecological, economic, and social) should all be considered in ecosystem service assessments, because it increases the potential that research will inform applied decision-making in an equitable and more sustainable way (Dendoncker et al., 2014; Díaz et al., 2015; Jacobs et al., 2016; Langemeyer et al., 2016). Martín-López et al. (2014) called for integration of multiple methods in a way that provides "information about irreducible and incommensurable value dimensions." Scholte et al. (2015, p. 74) added that to achieve such approaches, "the integration of monetary valuations and ecological assessments with socio-cultural valuations does not only entail adding the different parts, but also entails capturing the interactions between them." In addition to incorporating the three value dimensions and understanding how knowledge of one dimension may inform another, it has been suggested that focusing on a broad range of ecosystem services across spatial scales, and effectively communicating results with a broad audience, can also increase the potential that research will best inform applied decision-making (Chan et al., 2012; de Groot et al., 2010; Deal et al., 2017).

These research needs nicely align with the requirements outlined in the 2012 Planning Rule (U.S. Department of Agriculture Forest Service, 2012), which is the guiding document for forest planners across the United States working on updating old forest plans. However, meeting these broad-reaching research needs requires integration across disciplines in both the natural and social sciences. As Jacobs et al. (2016, p. 215) asserted, "the complexity of real life application defy hopes for a methodological silver bullet." Although the importance of integrated approaches that address the above needs is well established, the development of such approaches is still in progress. As Hattam et al. (2015) noted, the majority of ecosystem services assessments focus only on a single value dimension (i.e. ecological, social, or economic), and even in situations where mixed-method approaches are employed, integration of the results from the assessment of all three value dimensions are rare.

This paper aims to contribute to the effort to develop ecosystem service assessments that integrate ecological, social, and economic valuations. The methodological approach presented herein is not unique in that it integrates all three value dimensions, as several others have performed such assessments (e.g., Bark et al., 2016; Berg et al., 2016; De Vreese et al., 2016b; Fontaine et al., 2014; Villegas-Palacio et al., 2016). The novel contribution of our stakeholder-driven approach is that it combines two important elements. First, the approach focuses on understanding different perspectives about the importance of ecosystem services and, as shown by Crouzat et al. (2016), investigating these different perspectives can highlight both tradeoffs and synergies. Second, the approach aims to ensure that the perspectives highlighted and thoroughly investigated are broadly representative of the population of interest. The context within which this approach was designed is USFS National Forest decision-making, but the approach is broadly applicable to natural resource management focused on providing a spectrum of ecosystem services (e.g., oil and natural gas extraction, non-motorized recreation, and biodiversity conservation). Specifically, the potential benefits yielded include:

- a focus on inclusiveness, whereby multiple disparate stakeholder perspectives about importance of, and tradeoffs between, ecosystem services ('preference heterogeneity' in economic parlance) are discovered and investigated;
- a holistic research process where the different 'valuations' (i.e. ecological, economic, and social) inform one another, both in process and results interpretation;
- a structured and replicable research process, which can potentially be adopted (partly or wholly) to support forest management and planning;
- the integration of multiple spatial scales;
- a prioritization of select ecosystem services while not losing sight of the holistic picture; and
- additional confidence in decision-making and development of a foundation of knowledge about agreement and disagreement regarding ecosystem services which may facilitate public relations.

It is important to stress that this approach is not necessarily superior to other high-quality and rigorous approaches (e.g., De Vreese et al., 2016a; Fontaine et al., 2014; Martín-López et al., 2014). Instead, we emphasize that this approach should be added to a repertoire of approaches, which may be more or less appropriate to others depending on the context. We agree with Martín-López et al. (2014, p. 227) that "ecosystem service research needs as much variety of methods as complexity and value plurality exists in the system we want to analyze."

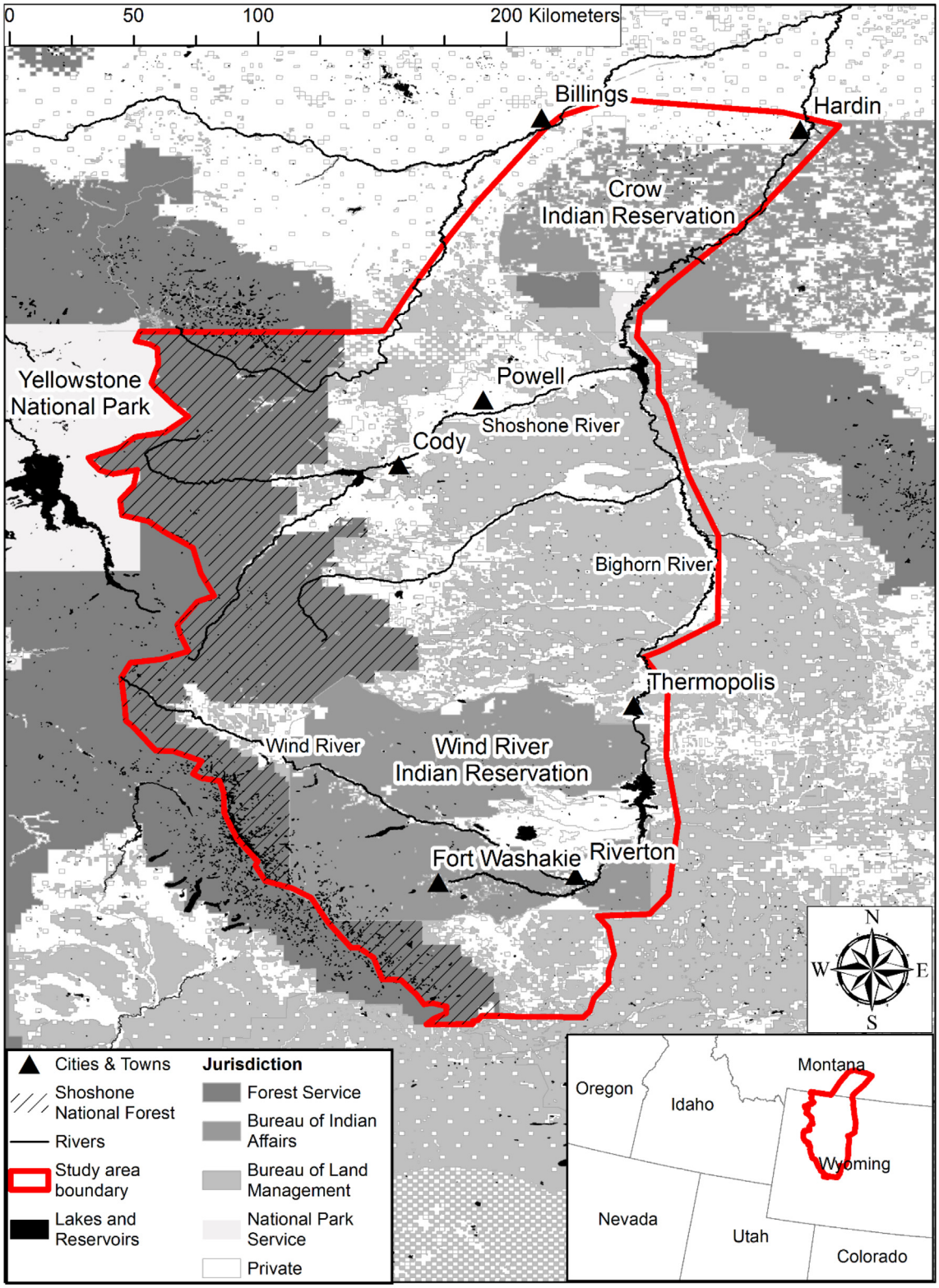
In a natural resources planning context, considering and accommodating multiple disparate stakeholder perspectives about what is important and what should receive scarce management and planning attention is paramount. Our approach is designed to assist the USFS in fulfilling their mission of "caring for the land and serving people" through "listening to people and responding to their diverse needs in making decisions" (US Department of Agriculture Forest Service, 2017).

This paper proceeds as follows: section two describes the study area where this integrated approach was applied; section three explains the methods integral to this holistic approach; section four presents results; section five provides a discussion of the strengths and limitations of this approach within the context of National Forest decision-making and; section six concludes.

2. Study area

This integrated approach to understanding the importance and tradeoffs related to ecosystem services is based on research from the Wind-Bighorn River Basin (the Basin) in northwest Wyoming and southcentral Montana, USA. The Basin, illustrated in Fig. 1, is similar to many regions of the intermountain western United States as: the majority of the land is managed by federal, state, and local government agencies; local residents often rely economically on natural resources (both through extractive and tourist-based industries); it has a snow-driven hydrologic cycle; and topography, vegetation, and climate are variable.

The topography within the study area ranges from rugged high elevation mountains (maximum elevation of 4207 m) to sagebrush flats (minimum elevation of 819 m). Predominant vegetation zones include: the alpine vegetation zone, which is typically composed of rugged, rocky terrain supporting shrubs, grass and forb species; the sub-alpine vegetation zone, which supports a number of tree species, including whitebark pine (*Pinus albicaulis*), subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and lodgepole pine (*Pinus contorta*) and; the montane vegetation characterized by Douglas fir (*Pseudotsuga menziesii)* (Rice et al., 2012; United States Department of Agriculture, 2009). The climate in the Basin can generally be described as a high-elevation semi-arid desert, with annual precipitation ranging from 13 cm on the valley floor to 180 cm in higher elevations (much of it in the form of snow) (MWH Americas Inc et al., 2010; Rice et al., 2012). The extensive system of rivers and lakes in the Basin support a diversity of aquatic species, including both native (Yellowstone cutthroat trout – *Oncorhynchus clarkii bouvieri*) and non-native (brown trout – *Salmo trutta*) trout species. The majority of higher elevation steams in the Basin, many of which lie within the Shoshone National Forest, are in good condition in terms of sedimentation and



Source: Armatas *et al.* (2017)

Fig. 1. Study area map of the Wind-Bighorn BasinSource: Armatas et al. (2017).

biogeochemical cycles (Rice et al., 2012); however, water quality conditions on the valley floor, which are more influenced by human activities such as agriculture, are more variable and include several river reaches designated as 'impaired' (Wyoming Department of Environmental Quality, 2012).

The physical, economic, and socio-cultural landscape is shaped by a variety of forces, including a history of homesteading and agricultural development dating back to the late 1800s, three sovereign Native American tribes (i.e. Eastern Shoshone, Norther Arapaho, and Crow) who reside partly or wholly in the study area, and domestic and

international visitors interested in the picturesque and biologically diverse landscapes of the Basin and nearby Yellowstone National Park.

3. Methods

This integrated assessment of ecosystem services was primarily conducted between 2012 and 2016. The ecological assessment informed the social assessment which, in turn, informed the economic assessment.

3.1. Ecological assessment: a synthesis of climate research and data

The ecological assessment, completed by Rice et al. (2012), focused primarily on the Shoshone National Forest (SNF), which occupies 2.4 million acres (982,982 hectares) of the western portion of the Basin (as shown in Fig. 1). Their analysis relied on previously completed research and climate-related data (e.g. temperature, precipitation data) to understand the potential for change in ecological conditions. The assessment considered the following natural components: water and aquatic systems, water quality, glaciers, snow, wetlands, vegetation, invasive species, fire, insects and pathogens, wildlife, fish, and biochemical cycling.

Regarding each component, the authors first assessed the current conditions. For example, the current conditions of 'wetlands' included an overview of spatial extent of wetlands on the Forest, the unique functions that they serve (e.g., supporting rare plants, filtering water), and relevant drivers of change (e.g., water diversions, grazing). Second, the authors integrated an understanding of climate projections to assess how natural components (e.g. water and aquatic systems, glaciers, fish) of the system have changed over time and may change in the future. For instance, studies monitoring and modeling glaciers in the study area (e.g., Cheesbrough et al., 2009) combined with climate projections suggest that as glaciers melt there may be a short term mitigation of reductions in summer water supply accompanied by a loss in terrestrial habitat adjacent to glaciers (Rice et al., 2012). With this combined understanding, Rice et al. (2012) highlighted implications regarding the ability of the Basin's ecological components to support human well-being through continued provision of ecosystem services. For example, the authors' suggested that invasive species impacts could reduce opportunities for livestock grazing.

3.2. Social assessment: Q-methodology to elicit stakeholder perspectives on the importance of ecosystem services

A Q-methodology study was conducted for the social valuation of ecosystem services in the Basin, the full details of which are provided in Armatas (2013). Q-methodology is a structured approach to analyzing subjectivity (i.e., opinions held by people) with the goal of highlighting shared viewpoints regarding a research topic, particularly those topics that are highly debated (Barry & Proops, 1999; Eden et al., 2005). A brief overview of the method as it was applied in the Basin is provided here, but a full, detailed description of Q-methodology can be found in Brown (1980) and Watts and Stenner (2012).

3.2.1. Identify and define ecosystem services for social valuation

The ecological assessment highlighted ecological components related to water (e.g., snowpack, stream flow) as particularly vulnerable. This finding guided the social assessment to a focus on water and, as a result, the initial step was to identify and define the broad range of water-based ecosystem services that support people in the Basin. The general philosophy of this step was to identify any ecosystem service that may be relevant to society, regardless of researcher perceptions of importance *a priori*. Identification of ecosystem services was completed through a Basin-specific literature review, consultation with experts (e.g., natural resource managers, planners, and scientists), two focus groups in the study area attended by diverse stakeholders (e.g., ranchers, nature-based tourist operators, non-governmental organization representatives), and pilot testing.

3.2.2. Identify a diversity of stakeholders

The goal for the second step was identification of a diverse range of perspectives about the importance of water-based ecosystem services. In addition to the methods applied in the previous step (e.g., focus groups), participants were asked for referrals to other people who could potentially provide different opinions about the importance of water-based ecosystem services. It is important to stress that the overarching goal was to develop a 'purposeful sample' that included a diversity of opinions about the importance of water-based ecosystem services. As a result, the conclusions developed are not representative of the general population at large and, therefore, this method alone does not allow understanding how particular perspectives are distributed across the population.

3.2.3. Recruit participants for valuation exercise and drivers of change discussion

First, participants were asked to rank the ecosystem services identified in Step 1. Fig. 2 illustrates the structure of the ranking exercise, also known as the Q-sort. Participants were asked to select their two 'most important' ecosystem services, followed by their next three, and so on until the entire Q-sort is complete. The Q-sorting process requires participants to decide those ecosystem services that are: most important or positively salient (i.e. right portion of Fig. 2); most unimportant or negatively salient (i.e. left portion of Fig. 2) and; perhaps neutral or lacking salience either way (i.e. middle of Fig. 2).

Second, a short follow-up interview was conducted with each participant to collect information about the ecosystem service rankings as well as drivers of change perceived to be influential to the participant's ability to receive their two 'most important' ecosystem services.

3.2.4. Data analysis and interpretation

Data analysis requires factor analysis, including varimax rotation, of all the Q-sorts collected (Brown, 1980). This process allows the analyst to pare down the large number of unique stakeholder perspectives into a limited number of typified viewpoints or archetypes. Each archetype is expressed with a 'factor array', which is a Q-sort defined by all those participants that load onto a particular factor. In other words, each archetype is defined by those participants who share a similar viewpoint regarding the topic of interest. Each perspective provides a nuanced understanding of what ecosystem services are important, those that are considered unimportant, and those that are less salient. These perspectives can also provide an understanding of the disparate perceptions regarding the tradeoffs among ecosystem services.

3.3. Economic assessment: Market and non-market values of ecosystem services

Based on the results from the social valuation, several ecosystem services were further assessed using market and non-market economic valuation methods. Non-market valuation of specific ecosystem services was completed using the stated preference technique known as choice modeling.

Choice modeling (CM) allows estimation of the economic value of several separate attributes of an environmental good. For example, a stretch of river (environmental good) can be thought of in terms of separate valuable attributes including whitewater recreation, biologically diverse aquatic life, potential for hydropower generation, and inspiring scenic vistas. Choice modeling is described, both in theory and application, by Bennett and Blamey (2001), Hensher et al. (2005), and Holmes and Adamowicz (2003a). Economic value can be expressed in terms of one's preferences for trading off one attribute with another (e.g., whitewater recreation for hydropower generation), or for trading off one environmental attribute with a cost. A CM survey needs to

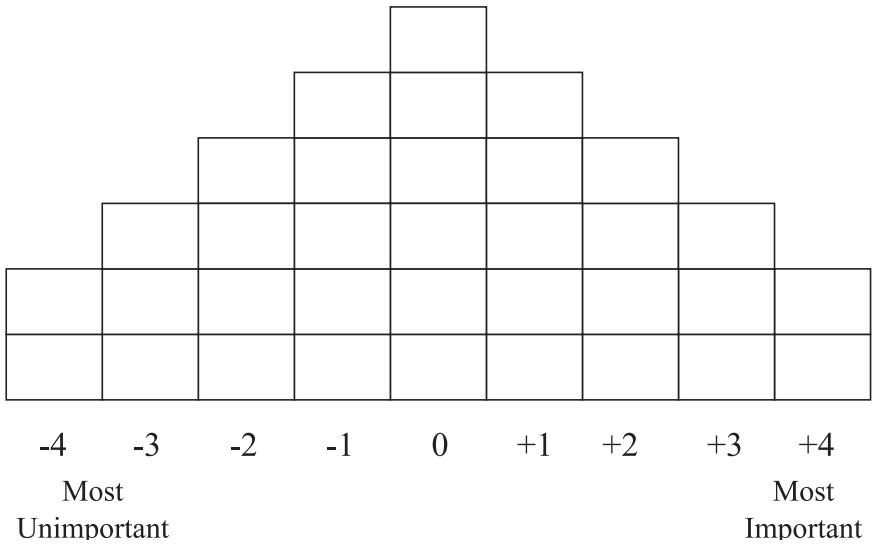


Fig. 2. Structure for ranking of ecosystem services.

Choice Set 1	Expected **outcomes** after 10 years		
Management Outcomes	Alternative A	NO CHANGE in Management	Alternative B
Agricultural community	550,000 acres irrigated	550,000 acres irrigated	600,000 acres irrigated
Angling	5% of streams are excellent	10% of streams are excellent	10% of streams are excellent
River and riverbank biological diversity	5% of streams are biologically diverse	15% of streams are biologically diverse	25% of streams are biologically diverse
Motorized winter recreation	50% open	40% open	20% open
Annual cost to my household	$300 ($25 monthly)	$540 ($45 monthly)	$840 ($70 monthly)
My household would choose (select one only)	☐	☐	☐

Fig. 3. Choice set example from survey instrument.

include a 'cost' attribute (e.g., a tax payment) to estimate monetary values.

Estimating the marginal change in the attributes of an environmental good is done by asking participants to compare hypothetical changes in those attributes in relation to the current state of the environment.

3.3.1. Survey instrument

The prior social assessment (i.e., Q-sort) provided a foundation for survey development, and was supplemented by a focus group, consultation with experts, and pilot testing. Our direct use of the social valuation phase provided several benefits including the identification of relevant and understandable ecosystem services, an understanding of when respondents may employ cause and effect reasoning (an undesirable survey completion tactic), as well as nuance and detail regarding the potential for protest responses. Details regarding the benefits of a structured approach to informing CM surveys using pre-survey social assessment are fully detailed in Armatas et al. (2014).

The final survey instrument included background information about the benefits of water provided by the Basin, questions regarding attitudes toward management of water-based ecosystem services, four 'choice sets' asking participants to select their choice of expected outcomes after 10 years, and demographic questions. Fig. 3 provides an example of a choice set, illustrating three different environmental scenarios. The column labeled "NO CHANGE in Management" represents the status quo, which is the current state of the environment included in all choice sets. Two alternatives are presented in which the ecosystem services and cost vary to create different scenarios.

Table 1 includes a definition of how each ecosystem service was measured, and the different levels of provision that were included in the choice sets. For example, the number of irrigated acres is the metric used to quantify 'agricultural community' (ACRES), and 550,000 acres is the status quo level. Development of the status quo levels assigned to each ecosystem service and the cost attribute was completed using available data, and the alternative hypothetical levels were developed based upon study area specific literature, discussion with experts, and best practices outlined in the choice modeling literature (e.g., Hensher et al., 2005). For instance, the estimate of the status quo for ACRES was calculated using the mapping software *ArcMap 10.1*, and this estimate was supported by statistics available in the 2007 Census of Agriculture (United States Department of Agriculture Census of Agriculture, 2007) and a Wyoming state water management plan specific to the study area (MWH Americas Inc et al., 2010). The alternative levels for ACRES were developed both through alternative agricultural growth scenarios in the water management plan, and through discussions with agricultural experts including irrigation district managers, farmers, and natural resource managers. Complete details related to the development of the levels for each ecosystem service and the cost attribute are available in Armatas et al. (2016).

3.3.2. Data collection

A mail-back survey was administered between March 17th and May 7th, 2016 using the multiple contact method developed and revised in Dillman et al. (2014). Data collection was completed by Christensen Research using a random sample of mailing addresses in the Basin. Adult household heads were asked to complete the survey. Four mailings, as necessary to garner a response, took place: (1) an initial mailing including a survey packet with 9 × 12 inch envelope stuffed with a cover letter, questionnaire, and a postage paid 6 × 9 inch return envelope; (2) a post-card reminder; (3) a second survey packet and; (4) a final survey packet.

3.3.3. Data analysis with a focus on preference heterogeneity

The choice modeling (CM) data are analyzed using both a multinomial logit model (MNL) and a latent class logit model (LCL). Both models have theoretical foundations based in random utility maximization (Mcfadden, 1973) and the characteristics theory of value (Lancaster, 1966). A detailed and technical description of analysis of choice modeling data, complete with econometric equations and discussion of utility components, is provided in Appendix A. Three econometric model specifications were fit to the data (i.e., two MNL models and a LCL model). Fundamentally, the models assess how the dependent variable (i.e. probability of choosing an environmental state, or a column in the choice sets) is influenced by explanatory variables. The models also include an 'alternative-specific constant', which accounts for variation in respondent choice that is not explained by the levels of attributes. Sometimes referred to as "status quo bias", this phenomenon results in decision-makers selecting the status quo at a rate higher than would be predicted by an economic model of consumer decision making (Samuelson & Zeckhauser, 1988). While failing to account for this effect can result in model estimates that overstate the magnitude of attribute coefficients (Samuelson & Zeckhauser, 1988), in this case, the effect is believed to be the result of a true preference for the status quo, rather than respondent bias, as discussed further in Section 5.1.5.

The explanatory variables in a 'base MNL' model correspond with the environmental attributes (Table 1) only, while a 'MNL-interaction' model and the LCL model include additional explanatory variables related to socio-demographics and attitudes (see Table 2). The attitudinal variables (i.e., ENVIRONMENT, RECREATION, AGRICULTURE) asked respondents to select their three 'most' important ecosystem services and three 'least' important ecosystem services, respectively. Appendix B provides exact details for how the attitudinal variables were defined but, in general, these variables were defined by integrating the findings from the social assessment. That is, based on the typified perspectives regarding positively and negatively salient ecosystem services discovered in the social assessment, attitudinal variables were developed to represent each perspective. Upon reading the results below, the reader will see that the social assessment identified *four* typified perspectives; whereas there are only *three* corresponding attitudinal variables in the economic assessment models. This is because the 'Native American' perspective in the social assessment was not found in the economic assessment. The implications of this missing viewpoint are detailed in the discussion.

Regarding the LCL, models ranging from 2 to 6 classes were run and a specification with 3 classes was selected as the preferred model. Selection of the number of classes was informed by *a priori* assumptions about the underlying elements of the heterogeneity (i.e., typified perspectives identified in the social assessment phase), as well as the statistical measures of model goodness-of-fit including Bayesian information criterion (BIC) and Akaike information criterion (AIC) (Swait, 1994).

4. Results

4.1. Ecological assessment

With regard to a broad range of ecological components (e.g., fire, invasive species, water quality, biochemical cycling), the ecological assessment completed by Rice et al. (2012) provided an understanding of how current conditions and the potential effects of a changing climate may influence the continued provision of ecosystem services. Those potential implications are outlined in Table 3, which highlight how the capacity of natural systems in the Basin to support human well-being may change. For instance, changes in the timing of spring runoff are expected to reduce summer river-related recreation opportunities, while a reduction in the amount of water quantity could decrease agricultural production and hydropower generation. Although stream temperatures are expected to increase and, as a result, reduce the amount of available habitat for particular aquatic species, such as the Yellowstone Cutthroat Trout (*Oncorhynchus clarkia bouvieri*), Rice et al. (2012) noted that the ecological conditions of the SNF, including its high elevation habitat and micro-climate conditions, may mitigate this effect by providing habitat refuge.

Rice et al. (2012:49) concluded that "water resources are particularly vulnerable as warmer temperatures are projected to reduce snowpacks, increase evaporation, lengthen summer seasons, and start spring runoff earlier. Warmer temperatures are likely to lead to reduced stream flows, which are critical to habitat and reservoir storage for agricultural and human uses." It was this general conclusion, and the potential implications for ecosystem services outlined in Table 3, that guided the social and economic assessments toward a focus on water.

4.2. Social assessment

Guided by the ecological assessment and using the methods described above, 34 water-based ecosystem services were identified. Those ecosystem services are listed in Table 4, and following Hein et al.

Table 1
Definitions of ecosystem services and the cost attribute.

Variable[3]	Definition	Levels (status quo bolded)	Units
ACRES	Number of irrigated acres in the Basin	450,000; **550,000**; 600,000; 700,000	Acres
ANGLING	Percentage of stream miles in the Basin with excellent[1] angling	5; **10**; 20; 30	Percent
BIO	Percentage of stream miles in the Basin considered to be biologically diverse[2]	5; **15**; 25; 40	Percent
MOTOR	Percentage of national forest land open to motorized winter recreation in the Basin	20; 30; **40**; 50	Percent
COST	Average annual household water cost	300; **540**; 840; 1080; 1380; 1620	US dollars

Notes:
[1] The survey stated to participants that: "*Excellent* streams are those designated as 'blue ribbon' or 'red ribbon' in Wyoming, or in the top 25% of fishing quality in Montana. These designations are based on amount of sport fish per mile, types of fish present, and angler preference.
[2] The survey stated to participants that: "*Biologically diverse* streams are those where a diverse range of native fish, amphibians, and plants are present within the stream and on the banks. Often, a specific range of stream temperature contributes to biological diversity. Biological diversity may maintain ecological stability and resilience."
[3] The table replaces the attribute name provided to respondents (i.e., agricultural community, angling, river and riverbank biological diversity, motorized winter recreation, annual cost to my household) with the variable named used in statistical analysis and presented in the results section (i.e., ACRES, ANGLING, BIO, MOTOR, and COST, respectively).

Table 2
Indicator (dummy) variables used in CM related to participant attitudes and demographics.

Variable	Definition
ENVIRONMENT	If a respondent aligns with the 'environmental perspective' from the social assessment
RECREATION	If a respondent aligns with the 'recreation perspective' from the social assessment
AGRICULTURE	If a respondent aligns with the 'agricultural perspective' from the social assessment
AGE	If a respondent is born before 1964, the cutoff for a generation of people commonly referred to as baby boomers.
FEMALE	If a respondent is female
EDUCATION	If a respondent has educational attainment above a high school diploma

(2006), they are categorized as provisioning, cultural, or regulating ecosystem services. Table 4 only lists the ecosystem services title, but the participants involved in this social assessment were also given accompanying definitions for each ecosystem service. For instance, 'preserving livelihoods, lifestyles, and landscapes' was defined as the benefit of water in the Basin "used to support healthy agricultural communities and large working farms and ranches." Perhaps the least intuitive ecosystem service in Table 4, this benefit was identified as important during the focus groups in the Basin both because it represented the cultural importance of agriculture in the study area dating back to early homesteaders and because it was seen to provide a layer of protection against residential development.

To obtain a broad range of perspectives regarding the importance of the water-based ecosystem services identified in Table 4, a total of 96 stakeholders were recruited, including people from the private sector (e.g., fishing outfitters and guides, farmers, oil and natural gas workers, uncategorized citizens), non-governmental organizations (e.g., fishing groups, agricultural groups), tribal governments (e.g., fish and game, water engineers office), local government (e.g., county commissioners, county planners), state government (e.g., Department of Environmental Quality), and the federal government (e.g., natural resource scientists and managers).

Data analysis of the 96 Q-sorts yielded four archetypes, which are illustrated in Fig. 4. The factor arrays in Fig. 4 display how each archetype ranked the ecosystem services (based on weighted factor scores), and the numbers in each box correspond with the numbers assigned to the ecosystem services listed in Table 4. To facilitate discussion, each perspective was named based on the ecosystem services that were considered to be most important. For example, the 'environmental perspective' was named as such because eight out of nine regulating services were considered to be positively important.

Each of the four archetypes are *briefly* described below with the support of direct quotes from participants that aligned with each perspective. To help the reader process each perspective as it relates to Fig. 4 and Table 4, when specific ecosystem services from Table 4 are mentioned, they are italicized and accompanied by brackets with both the number for the ecosystem service in Fig. 4 and the value (column) ranking. For example, those who align with the agricultural perspective consider *commercial irrigation* [12, +4] as one of the two 'most important' ecosystem services; whereas those who identify with the environmental perspective consider *commercial irrigation* [12, −2] as relatively unimportant.

4.2.1. The environmental perspective

Those who express the environmental perspective generally view

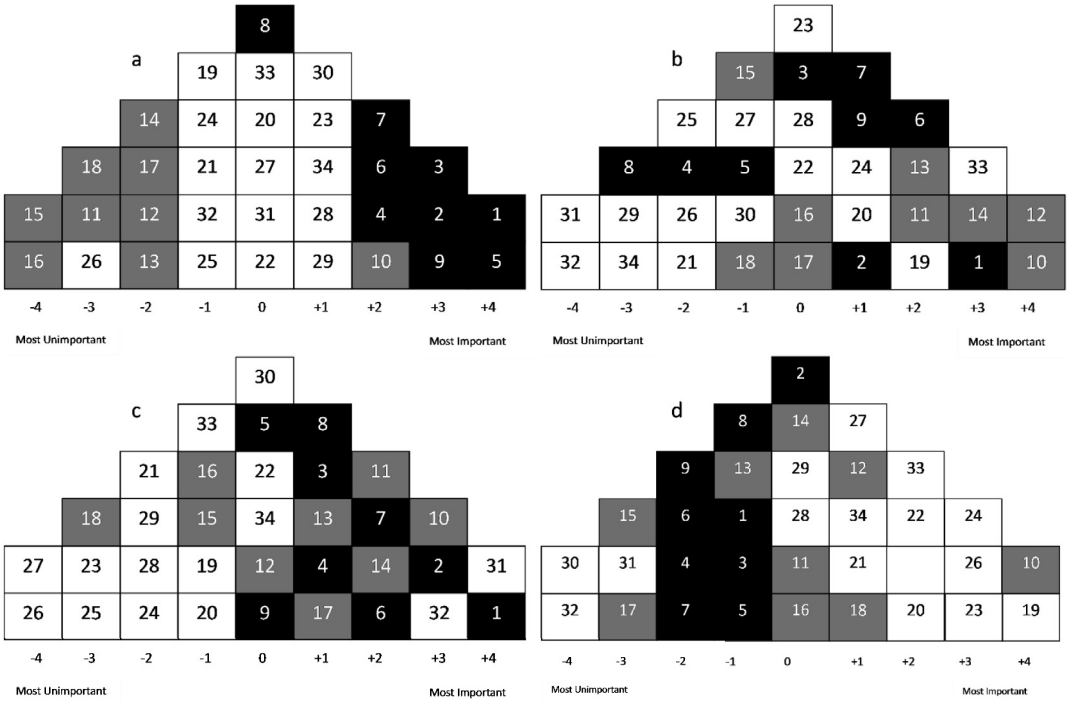
Table 3
Potential implications of changing ecological conditions for continued provision of ecosystem services.

Ecological Component	Potential consequences to ecosystem services
Water quantity	Increase in flood magnitude with degradation of aquatic habitat; loss of habitat for aquatic species from reduced streamflow; reduction of 5 to 25 percent of the annual water supply for water storage; reduction of up to half the annual water supply for human and agricultural use and recreation opportunities during drought; altered timing of water availability for storage; altered peak flows shifting or hindering salmonid spawning activity; altered timing of recreational opportunities— potentially earlier and shorter seasons for fishing, rafting, and kayaking; decrease in agricultural production and hydropower generation with reduced water supply
Water quality	Higher stream temperatures could potentially reduce the quality of aquatic habitat; increase algae; increased cost of water treatment
Glaciers & Snow	Existing glaciers may help mitigate reductions in water supply during summer; reductions in summer streamflow as glaciers disappear; loss of micro-site terrestrial habitat adjacent to glaciers; shift in suitability of aquatic thermal habitat; less annual water supply stored as snow and earlier release of stream flows for storage; loss of winter habitat for snow-dependent wildlife; reductions of recreation opportunities for skiing, snow shoeing, and snowmobiling, especially at lower elevations; increase in summer recreation and tourism opportunities
Wetlands	Loss of habitat for many species using or dependent on wetlands; alteration in local hydrology because of changes to, or disappearance of, wetlands
Invasive species	Increased competitive advantage for non-native fish over native species
Fish	Shifts or reductions in suitable salmonid habitat and associated fish species; reduction or loss of recreational opportunities for fishing native cold water species with the reduction in habitat quality and area; decrease in recreational fishing opportunities; high-elevation refugia for fish seeking cooler habitats

Source: Adapted from Rice et al. (2012).

Table 4
List of water-based ecosystem services considered in the social assessment.

Regulating ecosystem services		
1. Water quality	4. Conservation of rare plant species	7. Natural flood control
2. In-stream flow	5. Biodiversity conservation	8. Glacier-based services
3. Conservation of keystone (critical) species	6. Gradual discharge of stored water	9. Nutrient cycling and sediment transport
Production Services		
10. Household/Municipal water	13. Personal irrigation	16. Oil and natural gas extraction, and mining
11. Hydropower	14. Water for stock	17. Fighting forest fires
12. Commercial irrigation	15. Manufacturing and industrial	18. Supporting of commercial land-based recreation
Cultural Services		
19. River-based fishing	25. Commercial water-based recreation	30. Education, management and science
20. Lake/Reservoir fishing	26. Motorized ice and snow based recreation	31. Native American cultural and spiritual values
21. Lake, reservoir, and river-based hunting	27. Non-motorized ice and snow based recreation	32. Non-Native American cultural and spiritual values
22. Land-based hunting	28. Recreation/Leisure activities done near water	33. Preserving livelihoods, lifestyles, and landscapes
23. River recreation	29. Physically and mentally challenging recreation	34. Inspirational and aesthetic values
24. Lake/Reservoir recreation		



Note: Regulating ecosystem services are in black boxes; production services are in grey boxes, and cultural services are in white boxes

Source: Armatas *et al.* (2017)

Fig. 4. Factor arrays for the: a) environmental perspective; b) agricultural perspective; c) Native American perspective and; d) recreation perspective *Note:* Regulating ecosystem services are in black boxes; production services are in grey boxes, and cultural services are in white boxes Source: Armatas et al. (2017).

regulating services as important and production services as unimportant. The importance assigned to regulating services such as *water quality* [1, +4], *biodiversity conservation* [5, +4] *instream flow* [2, +3], and *conservation of keystone (critical) species* [3, +3] is due, in part, to the recognition of both the interconnectedness between these ecosystem services and their importance for supporting unique aspects of the Basin such as *river-based fishing* [19, +1]. For instance, Participant 14 explained the importance of *water quality* [1, +4] and the *conservation of keystone species* [3, +3]: "we have a reputation around here for being a world class, if not world class then national, fishing destination and the cutthroat trout has a huge profile and, because of that, if we lose one or more of those species it is going to significantly alter the ecosystem."

The unimportance assigned to most production services is due partly to the perceived tradeoff such benefits may force with important regulating services. For example, Participant 51 asserted, "the thing we worry about most for *in-stream flow* [2, +3] would be the development of it for commercial or agricultural interests (*manufacturing and industrial use* [15, -4]; *commercial irrigation* [12, -2]; *water for stock* [14, -2])."

4.2.2. The agricultural perspective

Those who identify with the agricultural perspective place a high level of importance on ecosystem services related to agriculture, such as *commercial irrigation* [12, +4], *water for stock* [14, +3], and *preserving livelihoods, lifestyles, and landscapes* [33, +3]. For this perspective, water is the lifeblood of the agricultural community. As Participant 45 explained, it is "how most of us make our income." Participant 35 noted that the whole Basin is reliant on agriculture economically, from all "the industries that serve us like the fuel guy…to the parts man, and the

guy that fixes the tractor, and the guy that owns the tractor shop." Expanding beyond those directly connected to the agricultural industry, Participant 10 suggested that if the provision of *water for stock* [14, +3] declined, then "people would be forced to look outside the area or region for stock, so it would drive [beef] prices up." Agriculture is also integral to the history of the Basin, and that is highly important to this archetype. For example, Participant 35 explained that agriculture is "just part of the history…you look at the old photos and there is a doctor, but he also had a ranch. Or there is a dentist and he had a ranch."

This perspective is by no means anti-environment, as they recognize that "the reason we live where we do is because of the water running off the mountains" (Participant 45). However, particular tradeoffs between water for agriculture and water for other uses such as *biodiversity conservation* [5, -1] and *conservation of rare plant species* [4, -2] are thought to exist. Participant 31 commented: "increased pressure from conservation groups, fishing, instream flow and anything like that would influence the ability to use" water for agriculture.

4.2.3. The Native American perspective

People who identify with the Native American perspective consider *Native American cultural and spiritual values* [31, +4] to be sacrosanct, and water quality [1, +4] and instream flow [2, +3] is critical for maintaining such values. 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." A specific connection between cultural and spiritual values and water quality was made by Participant 85: "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."

The Native American perspective also stresses the importance of maintaining economic opportunity through important water-based ecosystem services such as *hydropower* [11, +2] and *water for stock* [14, +2]. Participant 81 highlighted the opportunities that the Crow Tribe has to develop hydropower, which could "provide local subsidized [lower] prices" or sold "if they can get on a grid."

In general, recreation-related ecosystem services are unimportant (e.g., *motorized ice and snow based recreation* [26, -4], *commercial water-based recreation* [25, -3], *river recreation* [23, -3]) to the Native American perspective, which is, in part, due to perceived tradeoffs with other more important ecosystem services. Of specific concern to Participant 84 was the development of a nearby recreation area, where a proposed road was threatening "the heart of our prime hunting grounds."

4.2.4. The recreation perspective

Those who align with the recreation perspective assign a high level of importance to recreation-related ecosystem services, including *river fishing* [19, +4], *motorized ice and snow based recreation* [26, +3], and *lake and reservoir recreation* [24, +3]. Recreation is important to this archetype because it provides opportunities for family bonding as well as economic stimulus to the Basin. Participant 23 remarked, "most of my water thing is recreating…my boys are more into hunting nowadays" (*land-based hunting* [22, +2]). Regarding the economy, Participant 41 asserted that motorized recreationists "usually have a little bit more expendable money" that they are willing to spend on fuel, recreation vehicles, and lodging. In addition, motorized winter recreation (i.e. snowmobiling) contributes to land management budgets through the "15 dollars per vehicle [cost] to use on federal land" (Participant 41).

The recreation perspective is concerned about ecosystem services thought to threaten recreation opportunities. Perceptions of too much regulation are perhaps why *education, management, and science* [30, -4], *rare plant conservation* [4, -1], and *biodiversity conservation* [5, -1] are considered unimportant. Participant 41 bluntly stated that "environmentalists and management" obstruct his ability to use public land for motorized recreation and elaborated that the trail system is shrinking: "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."

4.3. Economic assessment: A focus on non-market valuation

A thorough economic assessment of ecosystem service values should include both an understanding of market and non-market values of ecosystem services, and for such a broad ranging assessment we suggest considering those ecosystem services identified as salient in the social assessment (i.e., ecosystem services occupying the far left and far right of the factor arrays in Fig. 4). For this study, a review of existing data and research regarding several market values related to water-based ecosystem services was completed (e.g., county level data in the Basin shows that market sales of agricultural products was about $360 million in 2012 (United States Department of Agriculture Census of Agriculture, 2012)). However, this section focuses on the primary data collection regarding non-market values, which we feel is a critical but difficult aspect of an economic assessment of ecosystem service values.

4.3.1. Results of data collection: response rate and sample demographics

A total of 1200 households in the Basin were contacted with the survey mailings, and 310 surveys were returned. Data collection yielded a final response rate of 30.5%, after accounting for twelve refusals and an additional 184 initial mailings returned as undeliverable.

A common goal of survey research involving a random sample is to assert that the results yielded from the sample are representative of the population at large. This is somewhat complicated by the fact that the unit of analysis of this survey is the household. Although this approach is not uncommon in situations where financial decisions are included in the survey, the availability of census data at the household level is limited in comparison to the individual. Table 5 provides a comparison between household level statistics calculated at the zip code level for the Basin population with those of the sample.

The sample roughly aligns with the population of households in the Basin, though the sample is underrepresented by low income households and overrepresented by high income households. In addition, the sample is underrepresented by homes with children (i.e. individuals under 18 years old), and overrepresented by households being occupied by the owner. The discrepancy between the population and sample with regard to children in the household is likely due to the relatively older age reported by respondents (78.4% of respondents were born prior to 1964).

4.3.2. Preferences for non-market water-based ecosystem services

The two MNL models fit to the data include: (1) a base MNL, where respondent choice is explained solely by the levels of the attributes and the alternative-specific constant and; (2) a MNL interaction model, where sociodemographic and attitudinal variables are also included as interaction terms to account for preference heterogeneity. The results from these models are shown in Table 6.

First, the models show that, in general, the results are consistent with common sense expectations. For example, those with pro-agriculture viewpoints had stronger positive preferences for ACRES. Interpreting the positive and statistically significant coefficient on ACRES X AGRICULTURE, one can assert that relative to the base-case,

Table 5
Sociodemographic characteristics of households in sample and Basin population.

Characteristic (n = number of surveys out of 310 to provide demographic information)	Sample (%)	Study Population (%)
Average household size (n = 287)	2.32	2.62
Household Income (n = 269)		
Less than $25,000	8.2%	21.8%
$25,000–$49,999	26.4%	26.3%
$50,000–$74,999	24.2%	20.8%
$75,000–$99,999	15.2%	13.0%
$100,000–$149,999	17.1%	12.6%
$150,000–$199,999	3.4%	3.2%
$200,000 or more	5.6%	2.3%
Households with individuals under 18 years of age (n = 287)	20.2%	34.6%
Proportion of homes being occupied by owner (as opposed to renters)	89.5%	71.0%

Source: United States Census Bureau (2010).

holding the 'agricultural perspective' increases the probability that an alternative that increases acres from the status quo will be chosen, all else constant.

The second main point, although not directly reflected in the results, is that the estimation of average marginal willingness to pay[1] for the attributes in both the base MNL and MNL-interactions models did not yield any average marginal willingness to pay estimates that were statistically different than zero.

Although it could be suggested that this outcome resulted from a set of attributes that fostered feelings of apathy in the respondents, we assert that a more likely possibility is that the attributes may have been perceived both positively and negatively by the respondents.

In other words, zero average marginal willingness to pay estimates for both MNL models may be the result of preference heterogeneity in the form of contradicting preferences toward the attributes by different groups of respondents.

Some respondents view increases in the level of a given attribute as a good thing, while other respondents view increases in the level of the same attribute as undesirable. This potential occurrence may be reflected in a limited number of significant coefficients in the base model, as well as the significant coefficients for specific interaction terms (i.e., ACRES X AGRICULTURE, ANGLING X ENVIRONMENT, BIO X ENVIRONMENT, MOTOR X RECREATION).

The latent class logit (LCL) model, the results of which are shown in Table 7, highlights how the preferences vary across three different groups (i.e., classes). Recall that the social assessment phase identified 4 archetypes: recreation perspective, environmental perspective, agriculture perspective, and Native American perspective. Based on primary model specifications, the Native American perspective does not appear to be captured in the choice modeling data. However, the three classes in the LCL model coincide with the other three perspectives identified in the social assessment (i.e., recreation perspective, environmental perspective, agriculture perspective). Class-specific estimates of marginal willingness to pay with 95% confidence intervals are obtained for each attribute using Eq. (A.9) and the delta method, and are presented in Table 8. The delta method allows estimation of the standard error of a random variable, such as MWTP, by expanding the variable's function around its mean using first-order Taylor expansion and calculating the variance, assuming that MWTP is normally distributed (Hole, 2007).

Class 1 is the reference class, and class membership parameters for classes 2 and 3 are interpreted in relation to the reference class. The reference group is the smallest class, representing 9% of respondents with positive and significant average marginal willingness to pay for MOTOR and BIO. The reference class also has significant average marginal willingness to pay to move away from the status quo. Based on the positive preferences for MOTOR, lack of significant preference for

Table 6
MNL regression results: understanding preferences for the environment based on levels of ecosystem services, and socio-demographics and attitudinal characteristics.

	Base MNL		MNL Interactions	
	Coefficient	Std. Err.	Coefficient	Std. Err.
ACRES	0.000177	0.000647	0.000390	0.00227
MOTOR	−0.000898	0.00617	0.0292	0.0224
ANGLING	0.0365***	0.00648	0.0311	0.0199
BIO	0.0184***	0.00560	0.0344*	0.0207
COST	−0.000726***	0.000205	−0.00158**	0.000737
STATUSQUO	1.324***	0.114	1.141***	0.404
ACRES X AGE			−0.00170	0.00149
ANGLING X AGE			−0.0260	0.0176
BIO X AGE			−0.0450***	0.0145
MOTOR X AGE			−0.0466***	0.0171
COST X AGE			0.000835	0.000535
STATUSQUO X AGE			0.0466	0.304
ACRES X EDUCATION			−0.00139	0.00162
ANGLING X EDUCATION			0.0104	0.0156
BIO X EDUCATION			0.0203	0.0134
MOTOR X EDUCATION			−0.00828	0.0145
COST X EDUCATION			0.000756	0.000559
STATUSQUO X EDUCATION			0.341	0.273
ACRES X FEMALE			0.00111	0.00134
ANGLING X FEMALE			0.0140	0.0140
BIO X FEMALE			0.0211*	0.0122
MOTOR X FEMALE			−0.00828	0.0139
COST X FEMALE			−0.00117***	0.000436
STATUSQUO X FEMALE			−0.387	0.258
ACRES X ENVIRONMENT			−0.00244	0.00194
ANGLING X ENVIRONMENT			0.0655***	0.0174
BIO X ENVIRONMENT			0.0262*	0.0154
MOTOR X ENVIRONMENT			−0.0219	0.0182
COST X ENVIRONMENT			0.000493	0.000536
STATUSQUO X ENVIRONMENT			0.282	0.363
ACRES X AGRICULTURE			0.00488***	0.00154
ANGLING X AGRICULTURE			0.0130	0.0138
BIO X AGRICULTURE			−0.0161	0.0128
MOTOR X AGRICULTURE			0.0184	0.0146
COST X AGRICULTURE			0.000108	0.000494
STATUSQUO X AGRICULTURE			0.271	0.274
ACRES X RECREATION			−0.000264	0.00207
ANGLING X RECREATION			0.00345	0.0262
BIO X RECREATION			0.0114	0.0196
MOTOR X RECREATION			0.0333*	0.0200
COST X RECREATION			−0.00000800	0.000827
STATUSQUO X RECREATION			0.185	0.384
Log-likelihood	−1003.447		−859.295	
AIC	2018.894		1802.59	
BIC	2055.596		2056.59	
N	3351		3162	

Levels of statistical significance denoted as: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

[1] Average marginal willingness to pay and 95% confidence intervals for each attribute were estimated with 500 bootstrap iterations using the method described by Efron and Tibshirani (1986).

Table 7
Latent class model results.

	Class 1 Recreation		Class 2 Environment		Class 3 Agricultural	
	Coefficient	Std. Err.	Coefficient	Std. Err.	Coefficient	Std. Err.
Marginal utilities						
ACRES	0.00460	0.00912	0.000432	0.00150	0.00168	0.00140
MOTOR	0.372*	0.207	−0.0411***	0.0124	−0.00589	0.0111
ANGLING	0.171	0.157	0.0612***	0.0130	0.0481***	0.0126
BIO	0.154	0.0953	0.0380***	0.0116	0.00225	0.01099
COST	−0.0170*	0.00881	0.000451	0.000378	−0.00105**	0.000422
STATUSQUO	−5.163	3.144	0.732**	0.308	2.294***	0.202
Class membership parameters						
ENVIRONMENT	*Reference class*		3.110*	1.725	1.240	1.744
RECREATION			−0.298	0.864	−0.295	0.757
AGRICULTURE			0.530	0.617	0.813	0.540
AGE			0.188	0.665	0.519	0.588
FEMALE			−0.769	0.604	−0.966*	0.521
EDUCATION			1.099*	0.634	0.662	0.531
Constant			−0.209	0.836	1.128	0.715
Posterior membership probability	9.0%		26.8%		64.2%	
Log − likelihood	−810.04					
AIC	1684.09					
BIC	1877.61					
N	3126					

Levels of statistical significance denoted as: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8
Annual Household Marginal Willingness to Pay (MWTP), by Class.

Attribute	Class 1 (Recreation)			Class 2 (Environment)			Class 3 (Agricultural)		
	Mean MWTP ($)	95% CI ($)		Mean MWTP ($)	95% CI ($)		Mean MWTP ($)	95% CI ($)	
ACRES	0.27	−0.62	1.16	−0.96	−8.07	6.15	1.61	−0.77	3.99
MOTOR	21.92	14.72	29.13	91.30	−42.48	225.08	−5.63	−28.14	16.87
ANGLING	10.08	−0.83	20.99	−135.82	−382.38	110.73	46.03	11.67	80.39
BIO	9.06	3.29	14.84	−84.35	−253.67	84.97	2.16	−17.40	21.71
STATUSQUO	−304.61	−542.31	−66.91	−1624.92	−4097.25	847.40	2194.75	370.93	4018.57

BIO, and the negative (albeit insignificant) coefficients on RECREATION for class 2 and 3, we suggest that class 1 has some commonality with the recreation viewpoint identified in the social assessment.

Class 2 represents 26.8% of respondents with positive and significant preferences for ANGLING, BIO, and STATUSQUO, and negatively significant preferences for MOTOR. Relative to the reference class, members of class 2 are significantly more likely to have at least some college education and to have selected regulating ecosystem services as their most important and production services as their least important (represented by a positive and significant coefficient on ENVIRONMENT). Based on these findings, as well as the positive and significant preferences for ANGLING and BIO, negative significant preferences for MOTOR, class 2 appears to correspond to the environmental viewpoint identified in the social assessment phase. Notably, the significant preferences revealed in the estimated model coefficients do not translate to significant average marginal willingness to pay for any of the attributes for class 2. In fact, the signs on average marginal willingness to pay values for class 2 are contrary to the preferences revealed by the model coefficients. This is a result of the unexpected positive, but insignificant, coefficient on COST. Despite not being a statistically significant result, this provides some evidence that members of class 2 may not have been concerned with the associated cost.

Class 3 is the largest class, representing the preferences of 64.2% of respondents with positive and significant average marginal willingness to pay for ANGLING, and for STATUSQUO, and negative and significant preferences for COST. Members of class 3 also have positive, but insignificant, average marginal willingness to pay for ACRES. Relative to class 1, members of class 3 are more likely to have selected agricultural-based ecosystem services (i.e., commercial irrigation and water for stock) as most important (positive coefficient on AGRICULTURE with $p = 0.13$), and are less likely to be women than members of classes 1 or 2. Based on the positive but insignificant average marginal willingness to pay for ACRES, the agricultural preferences expressed in preliminary survey questions, and the large average marginal willingness to pay for remaining with the status quo, class 3 appears to exhibit preferences that correspond to the agricultural viewpoint identified in the social assessment phase. The association between positive average marginal willingness to pay for STATUSQUO and agricultural preferences is explained by the fact that the levels of irrigated acres in the Basin are already quite high under the status quo. Therefore, expressing a strong preference for the status quo may represent a desire to not move away

from the high level of agricultural land use currently occurring in the Basin.

Further discussion of the economic assessment follows within later sections of this paper.

5. Discussion

The primary impetus behind this *integrated* assessment of ecosystem service values is to obtain a more complete picture of the story about the links between ecological components in the Wind-Bighorn River Basin (the Basin) and human well-being. The underlying implication of this approach, and other similar work, is that no single assessment (e.g., economic) is adequate on its own for the purposes of informing prudent decision-making within complex social-ecological systems. We have demonstrated how the results from the ecological assessment informed the social assessment, which then informed the economic assessment. In this discussion, we provide examples of this integration within the context of the potential benefits that this approach provides for Federal natural resource decision-making. Limitations and future research needs are also discussed.

5.1. Integration of results and the benefits for Federal land management

Integration of the results from the different assessment phases is particularly challenging for a number of reasons related to the philosophy of science (e.g., potential incommensurable epistemological assumptions). A discussion related to this challenge is beyond the scope of this paper, but it is acknowledged because this integration does not attempt to merge value metrics in any way. Instead, we aim to provide a rich story of the Basin that is not captured by any single assessment, but supported jointly by all three.

5.1.1. No perspective left behind

One clear benefit of this work for public land decision-makers charged with a multiple use directive is that it is, to the greatest extent practicable, inclusive. Voices that may not be captured by one assessment phase are found in another which, overall, provides a holistic picture of the diverse range of perspectives related to water-based ecosystem services. For instance, the Native American perspective that emerged in the social assessment was not found in the economic assessment. Our experience suggests that this occurred partly because the method used (i.e., random household mail survey) does not resonate with Tribal communities. A research collaborator with the Crow Tribe noted that even a $100 incentive would not persuade individuals to complete the choice modeling survey. Different methodologies not only engage different people, but also different perspectives and insight.

5.1.2. Issues of equity, fairness, and representativeness

Implicit within the goal of sustainable natural resource management on public land are concerns of equity and fairness, or concerns of resource distribution. Integrating the social and economic assessment of value highlights the different perspectives regarding the importance of ecosystem services. Decision-makers are provided with information about importance both in terms of representative samples and convenience samples, and when comparing the perspectives it is possible to see how a change in the provision of ecosystem services may result in a tradeoff related to human well-being. For example, an increase in opportunities for motorized winter recreation is likely to be beneficial to those who align with the recreation perspective; whereas the environmental and Native American perspective are likely to be negatively affected by such a change. This impact is represented in the positive sense both by the high value in the factor array for the recreation perspective and the positive average marginal willingness to pay ($21.92 per year).

In addition, considering both the social and economic perspective jointly provides insight into the question: “is the sample representative of the population?” In addition to suggesting, for example, that the sample was overrepresented by high income households and underrepresented by low income households, it is now possible to cautiously consider the sample from the economic assessment to be underrepresented by the Native American perspective.

5.1.3. Prioritization of select ecosystem services while not losing sight of the holistic picture

Decision-makers on public land in the United States have a nearly impossible task, which is to consider almost everything (i.e., ecological, social, and economic sustainability) with limited resources (both time and money). This approach narrowed down several ecological components to those related to water based on the understanding that they were particularly vulnerable. Through the social assessment phase, 34 water-based ecosystem services were then narrowed down to four attributes for non-market valuation. These four ecosystem services, as well as several others occupying the right and left side of the factor arrays in the social assessment in Fig. 4 (e.g., commercial irrigation, water for stock, Native American cultural and spiritual values), can be considered priorities by decision-makers due to their high salience to diverse stakeholders in the Basin. However, the positioning of these particular ecosystem services within the context of all 34 water-based ecosystem services allows decision-makers to maintain a more holistic picture emerging from input of people living in the Basin, not *a priori* assumptions about what may or may not be important.

Maintaining this broad understanding may be particularly important when comparing the results of the social assessment to the economic assessment, as it has been shown that decision-makers may favor monetary values over non-monetary values in complex decision-making contexts (Eppink et al., 2016). A common critique of the ecosystem services concept is that issues of ethics, intrinsic value, and other moral quandaries will be cast aside for the conceptually simple cost-benefit analysis. In contrast, we suggest that an integrated assessment encourages insights and considerations beyond a simple cost-benefit evaluation. Other tradeoffs can be examined and perhaps conflicting perspectives given attention.

A clear example of how this integrated assessment can facilitate this broad ranging consideration is the inclusion and expression of the Native American perspective. It has been suggested that cultural and spiritual values associated with indigenous peoples are not amenable to economic valuation (Venn & Quiggin, 2007), and our discussions with the Crow Tribe in the study area reinforced this suggestion. However, even if one attempted to include Native American cultural and spiritual values as an attribute in the choice modeling survey, there are several issues that would likely impede a “fair” assessment of such values. First, and relative to the economic assessment, the social assessment can better accommodate expressions of value associated with ‘kincentric ecology’ which, according to Salmón (2000:1332), is a viewpoint often held by indigenous people where humans and nature are considered as “part of an extended ecological family that shares ancestry and origins.” This viewpoint was evident in the follow-up discussion with Participant 58, who aligned with the Native American perspective. He explained that “everything has got a spirit, according to the tribal people…the rocks you stand on, the soil you stand on, the water you drink, the air

you breath, the sun, the moon, the owls…it is all within one society, and it makes up one society." Powerful sentiments such as this, which are perhaps the most common reason cited when discussing the incompatibility of economic methods for capturing particular values, are not easily incorporated into cost-benefit analysis.

A second issue with economic valuation of particular values, is that willingness to pay estimates are meant to be constrained by income, and this again puts some at a disadvantage. In 2014, at the national level in the United States, the median household income for American Indian and Alaskan Natives was $37,227, which lags far behind the nation as a whole ($53,657) (United States Census Bureau, 2014). While one does not need to be Native American to align with the perspective given its name, it is reasonable to assume that Native Americans are more likely to identify with this perspective. It is also worth noting that mitigating this potential inequity within non-market valuation techniques is the focus of ongoing research, including application of willingness-to-accept formats and adjusted willingness-to-pay estimates (e.g., Breffle et al., 2015). However, applying such mitigating strategies assumes that what is being valued *can* be valued monetarily, which is debatable in the case of cultural and spiritual values.

5.1.4. Integration of multiple spatial scales

The ecological assessment was focused primarily on the Shoshone National Forest (SNF), as the large public forest is critical to the provision of ecosystem services in the Basin and it is the spatial domain under which natural resource decision-makers have the most control. An improved understanding of how national forest land supports people in the Basin both on and off forest is potentially beneficial in two ways. First, at a narrow decision-making level, managers and planners may gain insight into landscape level approaches that provide benefits to different stakeholders. For instance, clearing a heavily forested portion of the SNF through a timber sale or fuel reduction project could potentially provide additional opportunities for motorized winter recreation and increase water quantity flowing off the Forest (though perhaps only in the short term). This latter effect could help those aligning with the agricultural perspective maintain the status quo and the vibrant agricultural community in the Basin. Of course, potential tradeoffs with other ecosystem services (e.g., biodiversity conservation) and the effects that may result to those aligning with the environmental and Native American perspective must also be considered.

The second benefit, which is perhaps most relevant at the policy level, is the ability to highlight the general importance of large protected areas in the Basin such as the SNF through its support of many different people in different ways. This assessment details that support with a level of nuance and scope that is potentially influential to the thinking of policy-makers and the public alike.

5.1.5. Proactive natural resource decision-making: Enhanced confidence and knowing the audience

Those responsible for administering the public land owned by all citizens of the United States are constantly confronted with decisions that would result in changes to the current approach. Individual forests and their planners are expected to update their 'forest plans' at least every 15 years, managers on-the-ground are often encouraged to apply 'adaptive management' which is meant to be a flexible style conducive to changing management approaches, and policy-makers are often looking to enact change to satisfy their constituents. Within the context of natural resource decision-making on public land, and the potential effects of those decisions on the provision of ecosystem services, it is prudent to consider how such changes may be received by different segments of society. If carefully used by decision-makers, the results yielded from this integrated approach can provide additional confidence in decision-making, help to align management objectives of those administering the land with the public, and provide valuable insight for the important task of building relationships with the public.

This benefit may be realized, in part, because the integrated approach can provide cross-validation of results. For example, the social assessment highlighted motorized winter recreation as positively salient to the recreation perspective, negatively salient to the environmental perspective, and less salient either way to the agricultural perspective. These same sentiments are reflected in the LCL results in Table 7, with the recreation class exhibiting a positive-significant preference, the environmental class exhibiting a negative-significant preference, and an insignificant result for the agricultural class.

Through an understanding of both tradeoffs and synergies between different perspectives, the depth of understanding gleaned from the social and economic assessment can also potentially allow for opportunities to foster social learning and civil discourse around natural resource planning and management. First, and with regard to conflicting viewpoints, consider the agricultural perspective (roughly represented by class 3) and the average household marginal willingness to pay to maintain the status quo of $2,195 per year. This is a staggering figure and the general message is clear: the agricultural perspective, as defined in the economic assessment, has a strong preference for the status quo. Commonly, a preference for the status quo is labeled a 'bias' as people in general resist change; however, the social assessment suggests that those adopting the agricultural perspective do prefer the current state of the environment in the Basin. Participant 31 in the social assessment was clear that we should remember that "the whole system was set up for commercial irrigation in the first place" and, Participant 23 added, that the Basin has a "vibrant ag community." There is further evidence that the Basin is currently well endowed agriculturally, including that 86–96% of private land in particular Basin counties are used for agriculture (Taylor et al., 2012). Maintaining the status quo and, consequently, the vibrant agricultural community, is important to the agricultural perspective for a myriad of reasons related to the economy, culture, and history of the Basin.

On the other hand, the marginal willingness to pay for the status quo for both the environmental perspective and the recreation perspective (as represented by class 1 and 2 in Table 8) are negative. Potential reasons for this conflicting perspective can be found in the social assessment. In the case of the environmental perspective, some perceive agricultural activities as leading to 'ecosystem disservices' which, according to Lyytimäki and Sipilä (2009:311), "can be perceived as negative effects of ecosystem degradation caused directly or indirectly by human activities." Two agricultural ecosystem services (i.e., water for stock and commercial irrigation) were considered 'unimportant' by the environmental perspective, and this negative salience is likely due in part to a perception of disservices. Participant 13, who aligned with the environmental perspective, asserted: "the second [the river] hits ranch land the water quality starts to fall apart."

Regarding potential synergies among viewpoints, this integrated approach can highlight agreement among the different perspectives in several ways. The social assessment may indicate particular ecosystem services that are universally important, unimportant, or less salient. This is the case for the ecosystem service related to water for household use, which is highly important to all viewpoints. As discussed above, the economic assessment showed that the recreation and environmental perspective shared a negative willingness-to-pay to maintain the status quo and, although the reasons for preferring a potential deviation from the status quo may differ, this common desire to see change could allow for productive discussion and debate.

Lastly, the information gathered during the follow-up interviews of the social assessment can highlight synergies between the different perspectives regarding other value dimensions underpinning preferences. For example, Jacobs et al. (2018) highlighted the value dimensions put forth by the Intergovernmental Platform of Biodiversity and Ecosystem Services (IPBES) as non-anthropocentric (intrinsic), instrumental (contribution to human quality of life), and relational (desirable relationships among and between people and nature). While this is a different conceptualization of ecosystem value than discussed herein (i.e., ecological, social, economic) and not the specific focus of investigation, the follow-up interviews may highlight common ground regarding such values even in cases where different ecosystem services are being discussed. For instance, those who align with the agricultural perspective commonly referred to the community benefits associated with agriculture, such as Participant 25 who lamented the loss of the "agricultural base" in the study area; while those who aligned with the recreation perspective often cited similar relational benefits stemming from recreation (Participant 23 reflected on the importance of maintaining family relationships through hunting activities, and Participant 41 made a similar point with regard to motorized winter recreation). Understanding these similarities across the different perspectives may be beneficial for developing productive dialogue and facilitating empathy within the decision-making process.

5.2. Limitations and future research needs

Although we consider this approach to be both valuable and practical within the context of natural resource decision-making on Federal land, there are limitations that are worth mentioning. The primary limitation on a practical level is the somewhat high financial cost and time needed to complete this integrated assessment. There is also the potential that the chosen order of the different assessments (i.e., ecological into social into economic) influenced our conclusions. Even though water is generally an important topic throughout the western United States, there is a possibility that beginning with the social assessment, for example, would have highlighted important ecosystem services and associated issues extending beyond water. As this study was conducted with an initial focus on ecological vulnerability, there is a chance that issues salient to the public not related to water were missed. Lastly, there are questions related to the ability of this assessment to inform actual decision-making. The benefits of this approach outlined above are largely theoretical, as we do not have any evidence that this information has influenced decision-making in the Basin (which may be partly due to a misalignment between decision-making timelines and the timeline of this assessment). The SNF completed its forest plan revision in 2015 and, at that time, the results from the ecological and social assessment were available to decision-makers, but not those from the economic assessment or the holistic integrated assessment.

We suggest that there is a need for future research that explicitly focuses on the link between more holistic assessments and decision-making within the context of Federal land management. In addition, this type of integrated assessment highlights potential benefits for furthering theoretical discussions such as the relationship between integrated assessments of ecosystem services and other similar types of assessments (e.g., integrated vulnerability assessments such as Schröter et al. (2005)), and the implications, from a philosophy of science perspective, of performing an assessment where multiple sets of assumptions are being applied.

6. Conclusion

This paper presented an integrated assessment of ecosystem service values and tradeoffs, which included information related to ecological value, economic value, and social value. The ecological assessment concluded that water-related components were particularly vulnerable and, based on this finding, the social and economic assessments developed an understanding of how water-based ecosystem services support human well-being in the study area. The approach was designed to understand multiple perspectives regarding the importance of ecosystem services, and four general perspectives were identified: environmental, agricultural, Native American, and recreation. This assessment can provide several potential benefits for the purposes of Federal natural resource decision-making, such as the inclusion of a broad range of perspectives, a holistic picture of important ecosystem services, and the potential for enhanced confidence when making decisions that diverge from the status quo.

Declarations of interest

None.

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Appendix A

A. Technical details of economic data analysis

Random utility explains that the utility associated with a particular alternative from a choice set is composed of both an observable and a random component,

$$U_j = V(x_j, p_j;\beta) + \varepsilon_j \tag{A.1}$$

where U_j is the true but unobservable utility associated with the consumption of profile j, V is the systematic indirect utility function, x_j is a vector of the attribute levels associated with profile j, p_j is the cost of profile j, β is a vector of preference parameters, and ε_j is a random error term. An individual will only select alternative i over alternative j if the utility associated with alternative i is greater than the utility from alternative j.

Assuming the errors in the regression can be described by a Gumbel distribution and are independently and identically distributed, the probability that an individual will select alternative i over alternative j can be expressed as

$$P(i|C) = \frac{\exp(\mu V_i)}{\sum \exp(\mu V_{j)}} \tag{A.2}$$

where μ is a scale parameter inversely proportional to the variance of the error term. By assuming constant error variance, this parameter can be set to equal one (Ben-Akiva & Lerman, 1985). This can be expanded and expressed as

$$P_n(i|C_n) = \frac{\exp(\beta_{ni}X_{ni} + \tau Q_{ni})}{\sum \exp(\beta_{nj}X_{nj} + \tau Q_{nj})} \tag{A.3}$$

where X_n is a vector of terms for the attribute levels encountered by individual n; β_n is a vector of associated estimated coefficients; Q_n is an alternative-specific constant, taking a value of 1 for status quo alternatives and zero otherwise, with an associated coefficient of τ.

In the model represented by Eq. (A.3), preference structures are assumed to be homogeneous across respondents, which may not hold true because there are individual characteristics that are likely to explain some portion of the preferences that people have toward environmental goods and ecosystem services. This assumption can be relaxed through the inclusion of individual-specific characteristics, R, that are interacted with the alternative-specific attribute-levels.

$$P_n(i|C_n) = \frac{\exp(\beta_{ni}X_{ni} + \tau Q_{ni} + \gamma R_n X_i)}{\sum \exp(\beta_{nj}X_{nj} + \tau Q_{nj} + \gamma R_n X_j)} \tag{A.4}$$

The latent class model (LCL), provides the ability to both, account for preference heterogeneity, and identify subsets of the population with similarities in preference structures. The LCL framework assumes that individuals are members of a group that has particular preferences, independent from the choice problem being analyzed, and that preferences differ across, but are homogeneous within, the groups (Swait, 1994). Given S classes in the population and individual n belonging to class $s(s = 1,\ldots,S)$, the indirect utility function can be written as:

$$U_{in|s} = \beta_s X_{in} + \varepsilon_{in|s} \tag{A.5}$$

where β_s is the vector of preference parameters for class s, X_{in} is a vector of individual and alternative specific characteristics and $\varepsilon_{in|s}$ represents the random component of utility for individual n of class s. The probability of individual n selecting alternative i is now partially dependent on what class of the population the respondent belongs to, with preference parameters varying by class:

$$P_{n|s}(i) = \frac{\exp(\beta_s X_i)}{\sum_{n=1}^{N} \exp(\beta_s X_k)} \tag{A.6}$$

Inclusion in a particular class is defined by socioeconomic, demographic and attitudinal characteristics. Described in Table 2, the characteristics included in the final model were selected based on significant predictors of preference that were revealed during data exploration and preliminary models that were informed by *a priori* assumptions from the findings in the Q-study.

As outlined by Holmes and Adamowicz (2003b), identification of class membership is accomplished through the following logit model:

$$P_{ns} = \frac{\exp(\lambda_s Z_n)}{\sum_{s=1}^{s} \exp(\lambda_s Z_n)} \tag{A.7}$$

where Z is a set of individual characteristics and λ is a vector of parameters. Selection of the number of classes is informed by the Bayesian information criterion (BIC) and Akaike information criterion (AIC) (Swait, 1994). *A priori* assumptions about the underlying elements of preference heterogeneity and the practical explanatory interpretation of the classes can also be taken into account.

The joint probability of individual n belonging to class s and selecting alternative i can also be defined as the expected value of the product of the probabilities defined in Eqs. (A.6) and (A.7),

$$P_n(i) = \sum_{s=1}^{S} [P_{n|s}(i)P_{ns}] = \sum_{s=1}^{S} \left(\frac{\exp(\lambda_s Z_n)}{\sum_{s=1} \exp(\lambda_s Z_n)} \right) * \prod_{k=1}^{K} \left(\frac{\exp(X_{ink}\beta_s)}{\sum_{j=n} \exp(X_{ink}\beta_s)} \right) \tag{A.8}$$

where $k = 1,\ldots K$ are the choice sets presented to individual i.

In order to obtain policy relevant interpretations of the estimated coefficients, the marginal effects of each attribute must be calculated. Based on the model represented by Eq. (A.4), the average household marginal willingness to pay (MWTP) for a one-unit improvement in any attribute can be estimated as

$$-\left(\frac{\beta_{n\ \widehat{attribute}} + \sum_{m=1}^{M} \gamma_{nm} G_m}{\beta_{n\ \widehat{cost}} + \sum_{m=1}^{M} \theta_{nm} G_m} \right) \tag{A.9}$$

where G represents the fraction of the study area population that falls into each of the m socioeconomic or attitudinal categories accommodated in Eq. (A.3), and all other parameters are defined as above. Based on the method used by Han et al. (2008), Eq. (A.9) produces adjusted average household MWTP that corrects for the potential that survey respondents were not representative of the demographic characteristics of the study area as a whole. From the estimated coefficients produced by Eq. (A.6), for each class *1* through S, MWTP for each attribute can be estimated as

$$-\left(\frac{\beta_{s\ \widehat{attribute}}}{\beta_{s\ \widehat{cost}}} \right) \tag{A.10}$$

B. Exact definition of attitudinal variables included in the economic assessment that represent viewpoints from the social assessment

The three attitudinal variables included in the models for the economic assessment (i.e., ENVIRONMENTAL, AGRICULTURAL, and RECREATION), where defined with the responses from the first two questions of the choice modeling survey shown in Fig. B1 below.

1) Rank the benefits related to water MOST important to you.

- **Place a 1 on the line next to the benefit most important to you;**
- **Place a 2 on the line next to the benefit second most important to you;**
- **Place a 3 on the line next to the benefit third most important to you.**
- **LEAVE ALL OTHER LINES BLANK.**

__ River fishing
__ Commercial irrigation
__ Cultural and spiritual use
__ Conservation of aquatic biological diversity
__ Hydropower
__ Household/drinking
__ Water for stock
Motorized winter recreation
__ Cycling of nutrients and sediment
__ Lake and reservoir recreation
__ Oil and natural gas extraction, and mining
__ Other (please list _____)

2) Rank the benefits related to water LEAST important to you.

- **Place a 1 on the line next to the benefit least important to you;**
- **Place a 2 on the line next to the benefit second least important to you;**
- **Place a 3 on the line next to the benefit third least important to you.**
- **LEAVE ALL OTHER LINES BLANK.**

__ River fishing
__ Commercial irrigation
__ Cultural and spiritual use
__ Conservation of aquatic biological diversity
__ Hydropower
__ Household/drinking
__ Water for stock
__ Motorized winter recreation
__ Cycling of nutrients and sediment
__ Lake and reservoir recreation
__ Oil and natural gas extraction, and mining
__ Other (please list _____)

Fig. B.1. Question 1 and question 2 from the choice modeling survey.

Based upon the answers to the questions in Fig. B1, the following indicator variables are defined as follows:

ENVIRONMENT = 1 if:

"conservation of aquatic biological diversity" *or* "cycling of nutrients and sediment" were indicated as most important (i.e., chosen in question 1)

&

"conservation of aquatic biological diversity" *and* "cycling of nutrients and sediment" were NOT indicated as least important (i.e., chosen in question 2)

&

"motorized winter recreation" or "oil and natural gas extraction, and mining" or "hydropower" were indicated as least important (i.e., chosen in question 2)

AGRICULTURE = 1 if:

"commercial irrigation" *or* "water for stock" were indicated as most important (i.e., chosen in question 1)

&

"commercial irrigation" *and* "water for stock" were NOT indicated as least important (i.e., chosen in question 2)

&

"cultural and spiritual use" *or* "conservation of aquatic biological diversity" were indicated as least important (i.e., chosen in question 2)

RECREATION = 1 if:

"river fishing" *or* "motorized recreation" *or* "lake and reservoir recreation" were indicated as most important (i.e., chosen in question 1)

&

"river fishing" *and* "motorized recreation" *and* "lake and reservoir recreation" were NOT indicated as least important (i.e., chosen in question 2)

&

"cultural and spiritual use" was indicated as least important (i.e., chosen in question 2)

Since the different perspectives in the social assessment were identified via factor analysis, the different perspectives are uncorrelated. Although it is not expected that the variables representing these perspectives would have a correlation of zero, one would expect them to have relatively low correlations. Table B.1 illustrates the correlations between the three variables.

Table B.1
Correlation between attitudinal variables.

	Environmental	Agricultural	Recreation
Environment	1.000	−0.3397	−0.0977
Agricultural	−0.3397	1.000	−0.0125
Recreation	−0.0977	−0.0125	1.000

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