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Involving Stakeholders' Knowledge in Co-designing Social Valuations of Biodiversity and Ecosystem Services: Implications for Decision-Making

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ABSTRACT

We contribute to addressing two gaps that reduce the utility of ecosystem sciences for decision-making: lack of standard methods for using stakeholders' knowledge to co-design ecosystem services science research, and absence of commensurable social valuation metrics that allow effective value comparisons. In two phases, we used co-designed instruments to conduct social valuation of biodiversity, and provisioning, cultural and regulating services. First, we conducted eight participatory fora, where experts and non-experts identified ecosystem aspects to which they ascribe value. We combined knowledge from the fora—expert and non-expert—and the literature to identify 45 ecosystem aspects of value—importance—to people. Second, we organized the valued aspects into four psychometric social valuation instruments that were reviewed and contributed to by experts and non-experts. We used those instruments in a survey questionnaire completed by 968 residents of Deschutes County, USA. Co-design led to high valuation reliabilities. The omission of either expert or non-expert knowledge would have resulted in suboptimal valuation. Unexpectedly, biodiversity was valued more than any category of ecosystem services, and urban sprawl regulation—a novel non-expert-identified function—was valued more than all aspects of climate regulation. These findings—directly resulting from co-design—illustrate that co-designed commensurable metrics are adaptable to various decision contexts; they can provide issue-specific valuations and comparisons, broader valuations, comparisons between specific and broader ecosystem services, and equity-based parameters for addressing distributional concerns vital to decision-making. Co-designed commensurable metrics lead to social valuations that are better suited for decision-making and for persuasive communication of those decisions to enhance social compliance.

Key words: psychometrics; reliability; validity; commensurability; legitimacy; behavioral compliance.

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Highlights

- Illustrated protocol for co-designing ecosystem services social valuation research
- Co-design leads to highly reliable and valid social valuations
- Co-design leads to novel important knowledge about ecosystem services valuation
- Co-design and commensurate valuation metrics enhance decision-making potential

Introduction

Bennett (2017) identified the use of stakeholders' knowledge in co-designing research as one of the major challenges to improving the utility of ecosystem services science for understanding and managing ecosystems. Co-design—involving both expert and stakeholder knowledge in developing research questions and addressing them—is an integral part of the co-creation of knowledge for sustainability (Mauser and others 2013). In general, co-design enables better support of local innovation processes (Bertheta and others 2016), is an agent of transformation for sustainability (Moser 2016), enhances scientific accountability to society (van der Hel 2016), and leads to greater research salience and legitimacy (Guimares and others 2016). Co-design can also help to better address decision-makers' most pressing needs (Bennettt 2017). But, there is little empirical evidence of how research co-design processes are structured and how they operate for ecosystem services management and decision-making.

Boeraeve and others (2018) recommend that valuations should begin with a participatory identification of ecosystem services, if the aims of such valuations are to enable integration of diverse values in decisions and facilitate effective actions. Successfully involving stakeholder knowledge in research co-design enables the emergence of knowledge that leads to better decisions (Bennett 2017). Laurans and others (2013) report that a significant amount of ecosystem services valuations are neither used nor useable in decision-making because they are inaccurate and incomplete. They argue that the entities measured in ecosystem services valuations are of little relevance to socially optimal decisions because they do not reflect the real issues that are at stake for decision-making. There are also lingering calls to make ecosystem services knowledge practical and useable to decision-making (Boeraeve and others 2018; Carpenter and others 2009).

In this manuscript, we address four main objectives. First, we describe the structural and operational elements of a process for acquiring stakeholder knowledge of valuable ecosystem services. We use focus group interviews to enable deliberative participatory identification of ecosystem aspects to which stakeholders ascribe value. By aspects of nature, we mean attributes of ecosystems that are features of biodiversity or are provisioning, regulating and cultural ecosystem services following the Millennium Ecosystem Assessment categories (MA 2005), e.g., the diversity of microorganism species and the variety of micro-habitats are aspects of biodiversity. Spiritual experiences, timber and pollination are aspects of nature that fit into the categories of cultural, provisioning and regulating services, respectively.

For the second objective, we describe the co-design process—how we combined stakeholder knowledge that emerged from the participatory identification process with expert knowledge from forest managers, scientists, and the literature to design psychometric social valuation instruments. Psychometric scales are instruments used to measure human phenomena such as knowledge, abilities, values, beliefs, attitudes, and traits (Furr and Bacharach 2014). The psychometric social valuation instruments were co-designed—instrument contents were generated by a combination of stakeholder and expert knowledge; stakeholders also pretested, reviewed and provided feedback on the instruments. Third, we describe how we used the instruments to conduct the social valuation of biodiversity and ecosystem services of the Deschutes National Forest (DNF) in Central Oregon, USA. Finally, we present what we learned from the participatory identification and the social valuation conducted using co-designed psychometric social valuation instruments and discuss some implications for decision-making.

The terms 'assessment' and 'valuation' are sometimes used interchangeably in the ecosystem services literature (Gopal 2016; Langemeyer and others 2017). In this study, we consider them as distinct. We use the term social value assessments to refer to the processes of identifying and inventorying the various aspects of ecosystems to which people ascribe value, and the term social valuations to refer to empirical estimations of the extents to which people ascribe value to particular aspects of nature. In the following section, we present additional justifications for co-design of biodiversity and ecosystem services social valuation instruments.

Additional Rationales for Co-design and Psychometric Social Valuations

Co-design is a critical element of social valuation instrumentation for two additional reasons—valuation validity and behavioral compliance with ecosystem services policies. With regards to validity, several scholars argue that co-design will result in more legitimate and effective decision-making (Raymond and others 2014; Bennett 2017; Boeraeve and others 2018). But, some important arguments for why co-design leads to more legitimate and effective decisions have not been well-articulated. The first of those arguments is that legitimacy is really about validity—that is, it is about ensuring that valuation instruments, approaches, or techniques actually measure what they purport to measure (Furr and Bacharach 2014). The basis of ecosystem services valuations in general is the assumption that nature is of value to people (Daily 1997). Hence, the aims for social assessments and valuations of biodiversity and ecosystem services are to identify aspects to which people ascribe value, and to determine the extents to which those aspects of nature are important to people (Costanza 2000).

When the aim for social valuations is to inform decision-making, two types of validity are most relevant. First, *content validity*—the match between what ought to be in the valuation instrument and what is actually in the instrument. Managers, other experts or research conducted in other contexts are often the basis of the content of ecosystem services valuation instruments (Asah and others 2012). It is illogical to assume that researchers or stakeholders alone know all that is of value to the subjects of social valuations. Therefore, valuation instruments must contain stakeholder knowledge about what is important to them (Bennett 2017). The second relevant type of validity is *face validity*, that is, the relevance of the content of valuation instruments to the subjects of social valuations. Face validity is most likely ensured when stakeholders identify and describe for themselves what is important to them, and whether the valuation instrument design enables their comprehension. To meet this criterion, stakeholders must contribute to the design of the valuation instruments. Validity improvement occurs when the contents of social valuation instruments are comprehensive reflections of expert knowledge, as well as the lived experiences of the subjects of social valuations (Sanna and Eja 2017). Because legitimacy originates from valid valuation processes, it is difficult to achieve without stakeholders' involvement in determining what is of value to them—participatory identification—and whether the valuation instruments are appropriate for their contexts. Hence, validity and legitimacy can be difficult to achieve without co-design.

Related to the legitimacy argument is the second understated justification for co-design: it enhances behavioral compliance with ecosystem services decisions (Cialdini 2007). Ecosystem management decisions often constitute and regulate human actions; they define 'who' (constitution) can do what and to what 'extent' (regulation) to ensure attainment of policy objectives (Asah and others 2014). Hence, behavioral compliance with ecosystem management decisions is an important consideration for decision effectiveness. Most decisions are only effective when people comply with the constitutive and regulatory aspects of those decisions. People are less likely to comply with decisions that require them to take actions for which the motivational goals appear inconsistent with their values or value priorities (Schwartz 1996). As essential behavioral antecedents, values are self-referential, though, in part, acquired through socialization (Schwartz 1994). Self-referential valuations of biodiversity and ecosystem services exist, in addition to, and irrespective of, expert perspectives (Schwartz and others 2012). That is, even without disciplinary expert knowledge, citizens still possess and use their discretion to determine what aspects of nature are important to them and act based on those values. What aspects of nature citizens consider important, and to what extents, may be different from those defined by experts alone. Consequently, decisions informed only by expert knowledge of values may be discordant with the values and value priorities (behavioral antecedents) of those expected to comply with those decisions, rendering such decisions less amenable to behavioral compliance, and hence less effective. This may explain the caution from Daily and others (2000) that values used in social decision-making should derive from those held by its individual citizens.

An important justification for using psychometric scales for social valuations of biodiversity and ecosystem services is that of commensurability, a precondition for effective value comparisons. An essential use of ecosystem services valuations is to inform ranking of decision alternatives (Blahna and others 2017; Primmer and others 2018), which necessitates value comparisons. Hence, we must be able to determine value priorities by effectively comparing valuations between and within various categories of ecosystem services. We must determine what aspects of nature are more or less valuable, to what extents and to whom. It is additionally important to enable effective comparisons of valuations of different aspects among various social units because the parameters for ecosystem services decision-making are primarily of a distributional or equity-oriented nature, often leading to perceptions of winners and losers (Laurans and others 2013). From a social valuations perspective, effectively addressing equity concerns requires proper determination of winners and losers. Hence, we must be able to determine and compare the values, and value priorities, of specific socio-demographic and other interest groups. This equity problem partially explains calls for integrated valuations that combine economic, socio-cultural and ecological valuations (Boeraeve and others 2018). But using different valuation approaches results in incommensurable ecosystem services valuation metrics, which renders such valuations less robust (Wright and others 2017). Metric incommensurability complicates decision-making by rendering comparisons of valuations, value priorities, and equity assessments to mere judgmental exercises. Attempts to use a variety of distributional weighting techniques to address the inequity problem has led critics to cite the difficulties in finding a consensus basis for formulating and quantifying equity weights (Turner 2007). Some decision-makers and analysts prefer certain methods over others making such weighting unfree of biases that may lead to inaccurate value comparisons (Primmer and others 2018). Hence, effective comparisons of social valuations—to enable proper rankings of decision alternatives and minimize inequity—require commensurable valuation metrics (Wright and others 2017).

Lastly, psychometric social valuations have the additional advantage of enabling assessment of valuation reliability. Reliability—the level of precision of valuation measures—is a necessary precondition for validity (Moss 1994; DeVon and others 2007), and therefore an important attribute of valid social valuations. Hence, legitimate decisions are difficult to achieve without valid valuations, which in turn depends on reliable valuations.

For this study, we used co-designed commensurable psychometric valuation instruments to conduct the social valuation of both tangible and intangible aspects of biodiversity and ecosystem services. The commensurable valuation metric allows direct value comparisons among: (1) main categories of ecosystem services and between these categories and biodiversity, (2) specific aspects of biodiversity and of categories of ecosystem services, and (3) different socio-demographic groups. We illustrate how value comparisons enable determination of citizen's value priorities to inform potential decision alternatives, highlight the nuances of equity issues that may arise from such decisions, thereby better informing trade-offs that typify ecosystem management decisions.

In a review of ecosystem valuations for decision-making, Laurans and others (2013) concluded that valuation methods and techniques still need improvements to enable more robust results that more accurately describe and distinguish the subject of its analysis. In illustrating co-design and commensurability, we also present details of methods and techniques used. We describe valuation subjects, compute the accuracy/reliability of valuations, and provide examples of the utility of social valuations using illustrated methods and techniques. By so doing, we hope to address some of the methodological and technical concerns about valuation raised in Laurans and others (2013) review.

Approach

The co-design process consisted of three core elements. The first element is how we acquired stakeholder knowledge using the participatory identification process. The second is the process of combining expert and stakeholder knowledge to co-design the psychometric social valuation instruments. As part of the co-design process, stakeholders also pretested, reviewed and provided feedback to the instruments. The third is how we conducted the social valuation process and analyzed the data. The study population was residents of the Deschutes County and the ecosystem of interest was the Deschutes National Forest (DNF) in central Oregon, USA.

Participatory Identification of Valued Ecosystem Aspects

We used a combination of focus group interviews (Krueger and Cassey 2000) and literature review for value elicitation, and to ensure comprehensive identification of the aspects of DNF to which people ascribe value. We identified expert and non-expert stakeholders by determining who benefits from the forest and whose actions likely affect the forest. So, we invited representatives of recreationists, tribes, local communities, decision-makers, regulatory institutions, environmental groups, NGOs, timber industry, managers and academia to participate in a deliberative collective identification of valuable aspects of the forest ecosystem. Stakeholders verbally confirmed their stakeholder group representation prior to the commencement of focus group deliberations. During participatory identification, we asked stakeholders what they valued about the DNF; that is, what about the forest is important to them. Focus group interviews enabled stakeholders to express the aspects of forest biodiversity and ecosystem services that they value in their own words and from their own frames of references. Self-referential value expressions ensured the capture of ascribed values through the lived experiences of representatives of the valuation subjects, thereby ensuring the face validity of the resulting valuation instruments (Furr and Bacharach 2014; Sanna and Eja 2017).

During each interview, we created an environment that promoted interviewees' comfort in the self-disclosure of aspects of nature to which they ascribed value. We used open-ended questions and non-directive interview moderation techniques thereby placing emphasis on the realities of interviewees and hence, freer articulations of various valued aspects of DNF (Krueger and Casey 2000). We used terms such as benefit, importance, and beneficial functions to probe for the elaboration of emergent valued aspects. The non-directive moderation technique enabled stakeholders to comment and respond to others, and to explain, re-visit and re-explain, thereby co-constructing valuable ecosystem aspects. The moderation technique also enabled saturation—that is, stakeholders exhausted their scopes of aspects to which they ascribe value, (Weiss 1994). The interviews were audio-recorded to further maximize comprehensive capture of valuable aspects of nature; it is difficult to concurrently take notes and engage with stakeholders without inadvertently missing some content of the deliberations including the exclusion of some valued aspects of nature (Krueger and Cassey 2000). After seven focus group interviews, we detected saturation—no new valued aspects of nature were emerging (Weiss 1994). We conducted an eighth interview to confirm saturation and hence content validity of the ensuing valuation instruments. On average, each interview lasted slightly over 2 h with seven (± 2) interviewees per session.

After verbatim transcription of audio records, we removed all identifiers prior to qualitative data analyses. The aim of qualitative data analysis, using NVivo software, was to ensure that all valued aspects of the DNF that emerged from interviews were included in the social valuation instruments. We read and re-read transcripts, and used In Vivo and Values coding (Saldaña 2013) to familiarize ourselves with stakeholders' use of language to express valued ecosystem aspects. We used deductive and inductive techniques for second cycle analyses. Deductively, the Millennium Ecosystem Assessment (MA 2005) classification served as the primary analytic guide. We iteratively searched the transcripts of stakeholder deliberations for expressions of valued aspects that matched the content of the MA classification. Inductively, we searched for texts that conveyed other valued aspects not identifiable in the MA. Although our focus was on ecosystem services, stakeholders repeatedly expressed five valued aspects of biodiversity, and many different valued aspects of the forest that fit into regulating, cultural and provisioning services categories, some of which are novel. However, stakeholders notably omitted several regulating services, such as pollination and regulation of pest, erosion and diseases (Asah and others 2012). We used MA and other literature references to check for and include otherwise missing valuable aspects of the DNF. Then, we assembled descriptive texts expressing valued aspects of DNF into four categories corresponding to biodiversity, and regulating, cultural and provisioning ecosystem services. We used the results of this process to co-design four psychometric social valuation instruments that were included in the survey questionnaire for the social valuation of biodiversity and regulating, cultural and provisioning ecosystem services of the DNF.

Co-design of Valuation Instruments

According to classical psychometric measurement theory (Furr and Bacharach 2014) and pertaining to social valuations, biodiversity and ecosystem services are social-ecological constructs (DeVellis 2017). That is, biodiversity and the major MA categories of provisioning, regulating and cultural ecosystem services are not directly observable but they are measurable through their manifest indicators; they are underlying phenomena that a set of indictors or manifest variables reflect (DeVellis 2017; Furr and Bacharach 2014). That is, there is no single directly observable entity called biodiversity; biodiversity is comprised of a series of directly observable/manifest features: number, distribution, and abundance of plant, animal and microorganism species. In psychometric measurement, these manifest features are indicators of biodiversity; individuals can indicate the extent to which each is important to them. Similarly, there are a multiplicity of features and processes that are collectively referred to as regulating services (e.g., pollination, air purification, and so on), provisioning services (e.g., timber, fresh water, and so on) and cultural services (e.g., recreation, cultural heritage, and so on). None of these features and processes reflect the entire category of the ecosystem services to which they belong. Hence, for the purposes of psychometric measurement, air quality, timber and cultural heritage are also manifest indicators of regulating, provisioning and cultural ecosystem services, respectively. Hence, a psychometric social valuation instrument for each construct is a collection of indicators (e.g., diversity of microorganisms) or specific ecosystem services (e.g., timber, pollination, and cultural heritage) designed to enable people to indicate the level of value ascribed to each (DeVellis 2017). The aggregate score of the levels of value ascribed to each indicator or specific ecosystem service within a construct (biodiversity or category of ecosystem services) constitute the valuation score for that construct. By using this classical psychometric measurement model, subjects of social valuations can rate the extents to which they ascribe values to specific manifest aspects of biodiversity, and specific provisioning, regulating and cultural services that fit into these three categories of ecosystem services (DeVellis 2017).

Using the psychometric measurement principles described in the previous paragraph, we designed four social valuation instruments, each corresponding to listings of statements or phrases that express individual valued aspects of biodiversity, and various individual regulating, cultural and provisioning services. The statements or phrases were such that social valuation subjects could easily assign numbers to listed aspects of biodiversity, and individual ecosystem services according to increasing levels of importance corresponding to different degrees of value ranging from 1 = not important to 7 = very important (Duncan 1984; Eastwood and others 2016). By so doing, the precise aim of social valuation—citizens' indications of the extents to which particular aspects of nature are important to them—is accomplished (Costanza 2000). The ratings are treated as interval type data because without labeling ratings 2–6, respondents infer equivalent distances between scores (McKenzie-Mohr 2011).

The instruments are co-designed because the listed aspects for each instrument are a combination of stakeholder and expert knowledge—interviews and use of the MA and other literature. By combining stakeholder and expert knowledge, we also boost content validity (Furr and Bacharach 2014). In listing valued aspects within each instrument, we preserved as much as possible, stakeholders' verbatim expressions to maximize face validity—respondents are likelier to be more familiar with the language that alike people used to describe those aspects when performing valuation ratings. To ensure that social valuation subjects (survey respondents) cued their responses directly on the extent to which each aspect were of value to them, we anchored response options directly on the importance of each aspect of biodiversity and ecosystem services, e.g., the prelude to the psychometric instrument for valuing biodiversity read as follows: Please, rate on a scale from 1 (not at all important) to 7 (very important) the extent to which each of the following aspects of the DNF are important to you (See supplementary materials for the psychometric instruments). By anchoring responses directly on importance (value), we minimize anchoring effects—what respondents are cueing their responses on (McElroy and Dowd 2007). Otherwise, these effects substantially undermine the validity and reliability of psychometric instruments by altering the ability of respondents to accurately perform valuation ratings (Tulving and Schacter 1990).

The most common words used by interviewees to describe regulating, cultural and provisioning services were 'functions', 'human benefits', and 'products' of DNF, respectively. To further enhance face validity, we used these words as preludes to the respective valuation instruments, e.g., the prelude to the psychometric instrument valuing regulating services read as follows: Please, rate on a scale from 1 (not at all important) to 7 (very important) the extent to which each of the following functions of the DNF are important to you. These preludes removed the need to explain what biodiversity and ecosystem services are and thus further minimized priming effects. Priming effects are stimuli that make some mental depictions temporarily more accessible and thence unconsciously more influential on rating tendencies (Schacter and Buckner 1998), thereby undermining the reliability and validity of valuations (Tulvig and Schacter 1990). Using words and phrases that originated and resonated with stakeholders further reduces the need for explanations and consequent priming effects.

Conducting Social Valuation

After developing the four instruments for the valuations of biodiversity and the three categories of ecosystem services, we assembled them into a questionnaire (See supplementary materials). We pilot tested the instruments by enabling selected stakeholders to complete and comment on various aspects of the questionnaire. These comments informed instrument modifications before conducting the actual social valuation—enabling subjects of such valuations to rate the extents to which they valued listed aspects of biodiversity and various ecosystem services. The questionnaire also contained questions assessing demographic variables such as levels of education, income, and gender. The participatory identification and valuation designs and protocols were reviewed and approved by the Institutional Review Board of the Human Subjects Division of the University of Washington, IRB approval #s 38074 and 47448, respectively. We used the 'tailored design method' (Dillman and others 2009) for social valuation. We sent the questionnaire to a random sample of home addresses in the Deschutes County. We followed up with non-respondents in three periodic reminders at two-week intervals: a post card reminder, a replacement survey, then another post card reminder. By mailing the questionnaires, we enable respondents to perform valuations at their discretion, thereby minimizing contextual influences on valuations and hence on reliability. We received 968 completed valuations for a response rate of 43%.

Data Analyses

We used Cronbach's (1951) coefficient alpha (α) analysis to determine the reliability or precision of the four valuation instruments (DeVellis 2017). The observed ratings/valuations of each aspect of biodiversity or various ecosystem services is a combination of the true rating plus error due to factors such as sampling and valuation imperfections, and problematic valuation protocols. A reliable social valuation instrument is one in which valuation error does constitute at most 30% of the observed rating scores for aspects of biodiversity or various ecosystems services within that valuation instrument. That is, precision measures of 0.7 and above—at least 70% of variance is attributed to the true valuation—are acceptable reliability (Nunnally 1978). We used the default Cronbach α analysis of IBM's SPSS software to determine reliability.

The four social valuation instruments are summated ratings scales (Spector 1992). That is, the aggregate score of the ratings of individual aspects of biodiversity, e.g., represents a measure of the relative social value of biodiversity. Use of summated ratings ensures computation of the overall value of biodiversity without compromising the ability to discern the relative valuation of individual indicative aspects of biodiversity. Respondents' overall valuation of biodiversity were obtained by computing the mean score of the ratings of all indicators within the biodiversity valuation instrument. We made similar computations to obtain overall valuation of regulating, cultural and provisioning services. Using the mean scores enable commensurate comparisons; we can compare social valuations of biodiversity with those of any category of ecosystem services and between ecosystem categories regardless of the number of indicative aspects in each valuation instrument.

We conducted some value comparisons to illustrate how metric commensurability facilitates effective determination of value priorities. We used pairwise t test to compare the social valuations of biodiversity, and regulating, cultural and provisioning services (Tabachnick and Fidell 2013). We also computed mean scores of the ratings of each of the aspects of biodiversity, and of various provisioning, cultural and regulating services. These mean scores enabled us to determine how respondents prioritize the values they ascribe to inherent aspects of biodiversity, and of specific regulating, cultural and provisioning services.

Finally, we compared valuations among demographic groups differentiated by the following criteria: gender, level of education and income, selected just to illustrate the potential equity implications of the method. Independent sample t test was used to test for valuation differences based on gender (Field 2013). ANOVA was used to test for differences among socio-demographic groups defined by income and level of education. We used Games-Howell post hoc test—appropriate for unequal variance and sample sizes—to test for differences between pairs within each socio-demographic group criterion (Field 2013). We used these parametric tests because the data met the assumptions for each test. We based our judgement of significant differences on a cut-off probability value of 0.05 (SPSS 19, stepping methods criteria).

Results

Valuation Reliability and Commensurate Value Comparisons

The instruments measuring biodiversity, and cultural, regulating and provisioning ecosystem services were of exceptional reliability with Cronbach α scores of 0.96, 0.92, 0.93, and 0.88, respectively—well above the 0.70 cut-off criteria for valuation reliability.

All pairwise *t* test comparisons were statistically significant (all *p*-values < 0.001). Respondents' overall valuation of biodiversity, and cultural, regulating and provisioning services were statistically significantly different (Figure 1). Biodiversity was valued significantly more than any category of ecosystem services. Although the difference between the social valuation of biodiversity and that of regulating services was small, that difference was not due to chance ($p < 0.001$). Regulating services was valued significantly more than cultural services, and provisioning services was valued the least.

Regarding individual aspects of the DNF, fresh drinking water was valued (mean valuation rating 6.67 on the 7-point scale) more than any other aspect of the DNF, followed closely by the natural beauty of the forest, air quality regulation, and recreation opportunities. Respondents value the variety of plants, animals and microorganisms slightly more than they value any other aspect of biodiversity. The genetic diversity of plants, animals and microorganisms was the least valued aspect of biodiversity but was valued more than all but one aspect of provisioning services—freshwater for drinking, and more than all but two aspects of cultural ecosystem services–the natural beauty of the forest and recreation opportunities.

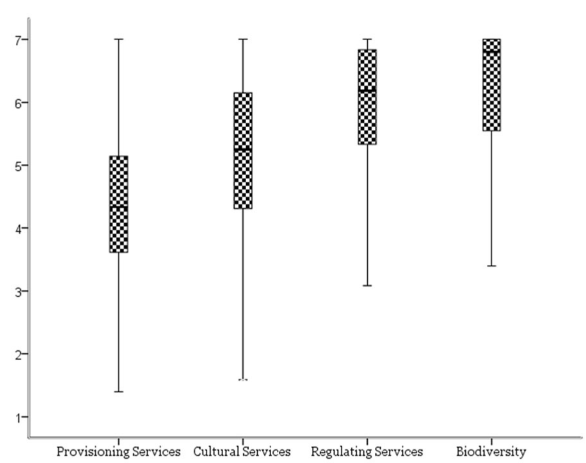

Figure 1. Pairwise comparisons of social valuations of biodiversity, and of regulating, cultural and provisioning ecosystem services (all pairwise comparisons were statistically significant, all *p*s < 0.001). Biodiversity was valued significantly more than any category of ecosystem services. Regulating services was valued significantly more than cultural services, and provisioning services was valued the least.

Water purification was valued more than any other aspect of regulating services. Of all aspects of regulating services, respondents ascribe the least value to moderating natural hazards like wind and storms. Respondents rated the esthetic values of the forest highest and the religious values the least of all cultural services. Respondents valued the provision of fresh water most and animal materials used for decoration the least, of all aspects of provisioning services. Regulation of urban sprawl was also valued more than all but one aspect of provisioning services—freshwater for drinking—and more than all but two aspects of cultural services—recreation opportunities and the natural beauty of the forest. See supplementary materials for tables showing mean valuations and respective standard deviations—overall social preferences—for each aspect of biodiversity and each regulating, cultural and provisioning services.

Socio-Demographic Group Comparisons

Women valued biodiversity ($p < 0.005$), cultural services ($p < 0.001$), and regulating services ($p < 0.001$) more than men (Figure 2). There were no significant gender differences in the valuation of provisioning services.

There were no significant differences in the valuation of cultural services among groups based on level of education, but there were significant differences in valuations of biodiversity ($p = 0.021$) and of provisioning ($p < 0.001$) and regulating ($p = 0.025$) services (Figure 3). Respondents who

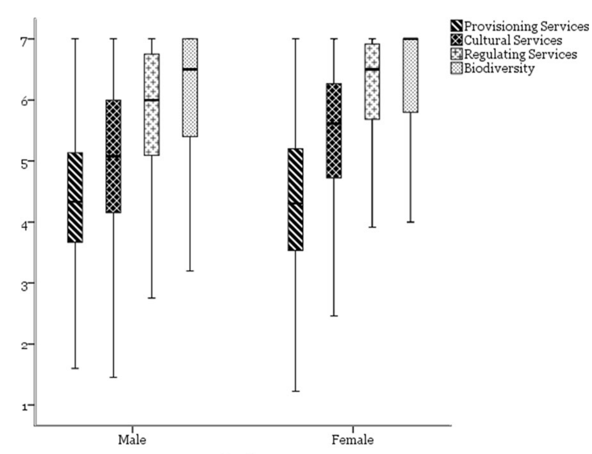

Figure 2. Gender differences in the social valuations of biodiversity and ecosystem services. Women valued biodiversity ($p < 0.005$), cultural services ($p < 0.001$), and regulating services ($p < 0.001$) more than men. There were no significant gender differences in the valuation of provisioning services.

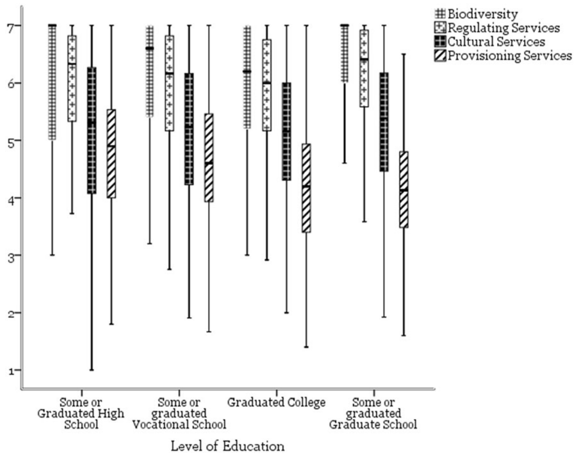

Figure 3. Differences in the social valuations of biodiversity and ecosystem services based on level of education. Respondents who attended some or graduated from high school and those who attended and graduated from vocational school valued provisioning services more than those who had at least an undergraduate degree (all ps < 0.001). Those who attended graduate school or hold graduate degrees valued regulating services significantly more than those who graduated college as their highest level of education ($p = 0.017$). Those who, at the least, attended graduate school value biodiversity more than those who attended or graduated from vocational schools ($p = 0.044$), and more than those who graduated college ($p = 0.008$). There were no significant differences in the valuation of cultural services.

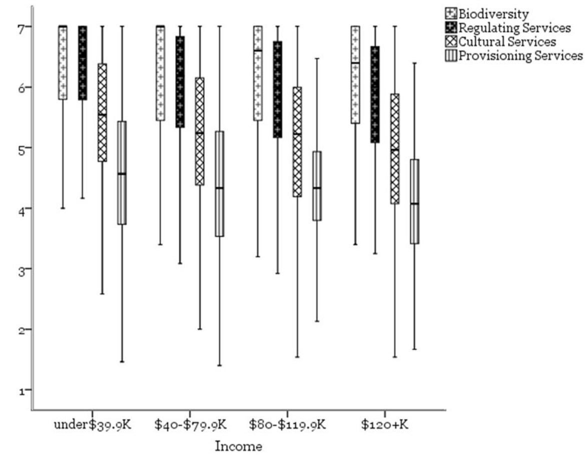

Figure 4. Income group differences in the social valuation of biodiversity and ecosystem services. Those with household income of $120 K + value provisioning services less than all other income groups: under $40 K ($p < 0.001$); $40 K–$79.9 K ($p = 0.008$); and $80 K–119.9 K ($p = 0.015$). Those with income under $40 K value regulating services significantly more than all higher income groups: $40 K-$79.9 K ($p = 0.014$); $80 K -$119.9 K ($p = 0.001$), and $120 + K ($p < 0.001$). Similarly, those with income under $40,000 value cultural services more than those in the income bracket $80,000–$119.9 K ($p = 0.021$), and those with income of $120,000 + ($p = 0.001$). There were no significant differences in the valuations of biodiversity.

attended some or graduated from high school and those who attended and graduated from vocational school valued provisioning services more than those who had at least an undergraduate degree (all ps < 0.001). Those who attended graduate school or hold graduate degrees valued regulating services significantly more than those who graduated college as their highest level of education ($p = 0.017$). Those who, at the least, attended graduate school value biodiversity more than those who attended or graduated from vocational schools ($p = 0.044$), and more than those who graduated college ($p = 0.008$).

There were no significant differences in the valuations of biodiversity among different income groups, but there were significant differences in the valuations of provisioning ($p < 0.001$), regulating ($p < 0.001$), and cultural ($p = 0.001$) services (Figure 4). Those with household income of $120,000 + value provisioning services less than all other income groups: under $40,000 ($p < 0.001$); $40,000–$79,999 ($p = 0.008$); and $80,000–119,999 ($p = 0.015$). Those with income under $40, 000 value regulating services significantly more than all higher income groups: $40,000-$79,000 ($p = 0.014$); $80,000-$119,999 ($p = 0.001$), and $120,000 and above ($p < 0.001$). Similarly, those with income under $40,000 value cultural services more than those in the income bracket $80,000–$119,999 ($p = 0.021$), and those with income of $120,000 + ($p = 0.001$).

In general, the most predominant determinant of differences in the social valuation of biodiversity was level of education. Differences in valuations of ecosystem services were more prominent between income groups than between groups differentiated by level of education.

Lessons Learned and Implications

In psychometric measurement, reliability is a necessary condition for validity (DeVon and others 2007). Given the high levels of reliability and extensive efforts to assure face and content validity, we cannot refute the assertion of valid valuations of biodiversity and ecosystem services of the DNF. The high reliability and consequent validity are direct results of using co-designed valuation instruments. Additionally, because the metrics are commensurate across all aspects of valuation content domains, decision-makers can systematically compare valuations in formulating decision alternatives. Finally, measurement comparability allowed us to evaluate value priorities across different social groups, which can help evaluate distributional impacts in order to understand sources of opposition and support for different decisions. We used gender, education, and income as sample group differentiating variables, but any socio-demographic categorization can be used, depending on the decision context, e.g., community differences, race or ethnic groups, occupational categories, tribal or organizational membership, and many others.

The method we present addresses many of the weaknesses in current approaches to ecosystem management valuations. Results show the possibility of developing and administering valid valuations that enable effective comparison of tangible (e.g., timber, clean water) and intangible values of ecosystems (e.g., spiritual, sense of place). It can be used for broad assessments of biodiversity and ecosystem services (in this case we used three MA categories) as well as for issue-specific contexts such as species habitats, extractive use regulations, restoration and land transfers. And finally, it can be an essential tool to help decision-makers conduct trade-off analysis. Rather than using incommensurate metrics (e.g., dollar values applied to timber production and to spiritual value losses that may be associated with timber harvesting), the metric commensurability across biodiversity and all categories of ecosystem services facilities direct value comparisons to more directly inform trade-offs.

We learned that stakeholders possess knowledge about ecosystem services that are novel to experts, further highlighting the essence of co-design through participatory identification (Asah and others 2012). Non-expert stakeholders identified the regulation of urban sprawl, a regulatory function that was not obvious to expert interviewees and in the scientific literature. And, urban sprawl regulation was valued more than six other well-known regulating services including all aspects of climate regulation that are more prevalent in the scientific literature. However, expert knowledge in instrument co-design is also critical. As shown in other studies (Asah and others 2012), and during the identification process, non-experts omitted several regulating services such as pollination; yet, pollination was the third most valued of regulating services. Moreover, regulating services were valued more than cultural and provisioning services despite omitting several aspects of regulating services during the participatory identification process. Hence, just because stakeholders do not identify certain aspects of nature does not mean that the omitted aspects are of lesser or no value to them. These findings substantiate claims that accurate valuation requires co-design—equivalent consideration of both non-expert and expert knowledge—if such valuations are to inform better decisions (Bennett 2017).

Valuations are used to raise awareness and inform decisions (Laurans and others 2013). Although the novel finding that urban sprawl regulation is a valued aspect of forests does not seem to have direct implications for conservation decisions, it may inform a more persuasive and hence effective articulation of decisions by emphasizing the positive effects of decisions on value priorities, e.g., expert knowledge may suggest hazard-regulating functions of the forest need improvements. But, the public prioritizes urban sprawl regulation over hazard regulation. It is unlikely that hazard regulation actions would alter the physical boundaries of the forest and its consequent function of regulating urban sprawl. Hence, decisions aimed at enhancing hazard regulation might be most appealing if the benefits of those actions on urban sprawl regulation (a value priority) are examined and articulated as part of the justifications for hazard regulation management actions.

Awareness campaigns that strategically articulate how management decisions and practices align with public value priorities may facilitate social compliance and minimize social upheavals that may undermine effective implementation of those decisions (Schwartz 1996). The same logic applies to other value priorities, especially the general observation that biodiversity is valued more than all categories of ecosystem services. Designing policies and management practices so that they address biodiversity values and articulating co-benefits to other value priorities such as water purification, recreation, and esthetics, may generate better public understanding of, support for, and compliance with, management decisions. Understanding value priorities can inform strategic targeting of specific groups with policy articulation messaging that most closely align with their value priorities. Hence, even if ecosystem services valuation results do not directly influence decision-making, they may improve social compliance through persuasive communication.

Distributional or equity concerns are a key parameter for ecosystem services decision-making (Laurans and others 2013). By using commensurable valuation metrics, we enable more direct and hence more effective comparisons of valuations across different interest groups. This ability to determine who wins or loses and to what extent is key to understanding the nuances of equity issues and the diversity of value priorities with which decision-makers must contend to make decisions and trade-offs (Turner 2007), e.g., biodiversity was valued higher than all ecosystem services categories by social groups differentiated by gender, level of education and income; this comparison suggest that decisions that undermine biodiversity will entail an across-the-board loss within the study population. But, because women valued biodiversity more than men, the loss will be perceived more severely by women than by men. The same is the case for regulating and cultural services. Similarly, the loss will be more in disfavor of those who attended graduate school compared to those who attended or graduated from vocational school and college. However, based on income—a key parameter of equity considerations—the across-the-board loss will not have inequivalent impact on any socio-economic social group because there were no significant differences in the valuation of biodiversity among social groups differentiated by income. Similarly, decisions that undermine the availability of provisioning services would have a stronger negative impact on those with lower levels of education and income. These nuances, albeit important for decision-making, may be less obvious or exaggerated when incommensurate metrics are used for comparing valuations (Primmer and others 2018; Wright and others 2017).

Another lesson with implications for decision-making regards defying both manager and expert presumptions of social values ascribed to ecosystems. Deschutes County is known for its lifestyle amenities and as a prime destination for retirees. On these bases, we expected/assumed cultural ecosystem services to be of highest priority. The managers who participated in the identification process also had similar assumptions; they mostly emphasized the cultural values to forest communities, but the social valuation findings show that these communities value biodiversity and regulating services significantly more than cultural services. Thus, despite operating in settings that facilitate frequent interactions with forest communities, managers' understanding of community's ecosystem services value priorities are different from the communities' realities about what is important. Discrepancies between actual social values and what experts and managers assume to know about social values of ecosystems have significant implications for ecosystem management. Managers' views about what is important to people tend to influence managers' decisions (Steelman and McCaffrey 2011; Asah 2014). Our findings suggest that without co-designed valuation of value priorities using a metric that enable commensurate comparisons, typical decision-making and trade-off judgements could be based on erroneous assumptions of public values.

The negative consequences of public responses to decisions based on mistaken assumptions of social values and value priorities cannot be overemphasized. What people value and prioritize influences their support for ecosystem management practices (Neugarten and others 2012). And, public support is crucial for effective ecosystem management, especially given the democratic underpinnings of ecosystems such as the national forest system. Not managing for what is important for forest communities is known to impede effective management for forest health (Kelly and Bliss 2009). People resist actions that are inconsistent with their values, especially when such values are of a higher priority than the motivational goal attainable through policy-prescribed actions (Schwartz 1996). Thus, social valuations of ecosystem services must facilitate decision-makers' ability to anticipate and manage social responses to policies—must be informed by reliable and valid social valuations, attainable through co-design.

One challenge in involving stakeholder knowledge in co-design, in contexts like with a national forest, is the practicality of identifying and involving all pertinent stakeholders. Essentially, ecosystem valuations are only as comprehensive as the stakeholders who were included in the design. Hence, it is possible that there are yet some valuable ecosystem aspects that are omitted. Our sample was also only of the immediate forest communities while, for some purposes, the entire nation may be stakeholders, and the valuation outcome may be different as we have shown that they are different even for different social demographic groups within the county. Additionally, no single method for valuing biodiversity and ecosystem services can fulfill the complete needs for a decision-making context; our approach is one tool. In addition to its utility in site specific contexts as illustrated in this manuscript, it is an approach with much broader utility, e.g., the method can be used for every national forest, and while individual aspects of biodiversity and specific types of ecosystem services will change from forest to forest as a result of the co-design process, reflective of different social-ecological contexts, the constructs of biodiversity and the main categories of ecosystem services remain the same. Hence, with commensurate metrics, social valuations with dissimilar contents of the instruments assessing biodiversity and main categories of regulating, cultural and provisioning services are still directly comparable between forests and among regions to inform national and regional science-policy considerations.

The instruments have different metrics from those used in economic valuation, and the results are more general, but the establishment of reliability, validity, and commensurability of value metric for biodiversity and all major categories of ecosystem services is a major advantage for many circumstances. Judgements about different valuation methods need to consider the purpose and context for doing the valuations (Blahna and others 2017). As we have shown, metric commensurability is also important for understanding the nuances around equity concerns that may guide trade-off decisions. Nevertheless, even with ideally comparable metrics, we recognize that psychometric social valuations is not the only source of information needed for decision-making. Once key issues and aspects of a decision with ecosystem service or biodiversity implications are identified additional and more targeted valuation data may be needed.

Conclusions

The purpose for this study was to use participatory identification of valued ecosystem aspects to co-design commensurable social valuation instruments, conduct social valuations of biodiversity and ecosystem services of the DNF, and discuss the lessons learned from the process. We have shown how to incorporate content and face validity in the identification of aspects of nature to which people ascribe value. We provide evidence that co-design leads to new knowledge that may inform better decisions and enable expert learning, and that stakeholder knowledge or expert knowledge alone is insufficient for valid valuations and consequent legitimate decisions. We show that citizens can assign numbers to both tangible and intangible aspects of ecosystems so that those numbers correspond to the relative extents to which they value those aspects resulting in highly precise and valid valuations. Without complex mathematical models and assumptions, we estimated with exceptional reliabilities the social valuations of biodiversity and ecosystem services of a particular ecosystem using psychometric principles and other social science techniques. We illustrate how such a process enables understanding citizens' value priorities for a wide variety of ecosystem aspects. Because the metrics are commensurate across biodiversity, and regulating, cultural and provisioning services, we provide a tool for facilitating effective determination of social equity concerns that may inform trade-offs in decision-making. Metric commensurability maximizes fairer decision outcomes because it minimizes the potential for biased subjective value comparisons across biodiversity and ecosystem services. We have also shown how co-design may lead to more complete and valid valuation instruments that can enhance persuasive articulation of decisions and broader social compliance, thereby rendering the decisions more effective.

Ecosystem service valuations are context dependent, but the process and measurement instruments developed here can be adapted and used as a decision aid in any social-ecological context. Interview protocols to uncover citizens' valued aspects of nature are straightforward, yet systematic and thorough. Specific aspects of biodiversity and ecosystem services can be added or excluded from the instruments as relevant, and the process of instrument development is actually *less* complicated than methods that result in incommensurable value comparisons. The other advantage of the co-design method is its breadth. Thus, while multiple methods of valuation are necessary, a generalizable approach would be to start with co-design method we describe here, then complement with other specific valuation techniques (e.g., monetary estimates) for detailed analyses as needed.

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