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Utilitarian and biocentric stakeholders' visual preferences for floodplain restoration heterogeneity

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1 Title

2 Utilitarian and Biocentric Stakeholders' Visual Preferences for Floodplain Restoration

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5 Riparian Restoration Visual Preferences

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13 AMD, BHD, BMC, KDH designed the research; AMD, BMC developed the survey
14 software; BMC collected the data and wrote the manuscript; KDH tested and provided
15 detailed comments on the survey; BHD, KDH reviewed the manuscript.

16 Keywords

17 Visual perception; social acceptance; riparian forest; habitat restoration;
18 interactive visual surveys; restoration aesthetics.

19 Abstract

20 **Introduction:** Many stakeholders care more about how a restored landscape
21 looks than about ecological design features, yet visual preferences for restored
22 landscapes have rarely been evaluated. Restoration projects could benefit ecologically

from incorporating more heterogeneity at the project's onset, but this impacts visual aesthetics.

Objectives: We evaluated the visual preferences for different types and levels of habitat heterogeneity of two stakeholder groups.

Methods: We developed a 3D interactive survey in Unreal Engine to evaluate participants visual perception of terrain variability, tree clustering, tree size variability, understory complexity, and large woody debris for riparian forests that were simulated from field and remote sensing data. Participants were grouped into either primarily biocentric (hiker, wildlife viewer, restoration ecologist) or utilitarian (fisher, hunter, farmer) land users.

Results: Both participant groups had similar preferences for an intermediate level of habitat heterogeneity, though results differed for certain features. Biocentric stakeholders preferred landscapes with more variable topography and tree size, greater understory complexity, and more large woody debris than utilitarian participants. Biocentric and utilitarian participants had similar definitions for natural and for cared for landscapes. Utilitarian participants' ideal understory complexity matched their definition of cared for, whereas biocentric participants' ideal matched their definition of naturalness and visual complexity.

Conclusions: Generally similar perceptions of landscapes by both utilitarian and biocentric participants may result from living in the same region. Nonetheless, their preferences differed slightly because of how each group moves through the landscape.

Implications for Practice: Interactive visual exercises provide a way to codesign restoration projects with community members and potentially increase project

acceptance, but require considerable resources to create and need to be accessible for community members. When restoration projects are in heavily human-utilized areas they should balance aesthetic preferences of stakeholders and the regional cultural context shaping their landscape perception. This may require mowing or masticating understory vegetation in areas where visitors go off trail or near human developments where a visually messy understory is undesirable. Intermediate levels of heterogeneity can improve visual acceptance of riparian forests. People prefer large trees so restoring forests around existing large trees may provide visual, as well as ecological, benefits.

Introduction

Most ecological restoration projects focus on ecological outcomes (Martin & Lyons 2018) though there have been repeated calls for the importance of engaging stakeholders throughout the restoration process (Shackelford et al. 2013; Jellinek et al. 2019; McAfee et al. 2021; Löfqvist et al. 2023). Restoration actively trades off between different ecological and social objectives depending on the landscape condition and the local context (Brancalion & Holl 2020). These social objectives can include local context such as historical use of an area, shared understanding of what is considered an aesthetically pleasing landscape, and the ability to use the area for local events and recreation. Stakeholder engagement can better integrate ecological and social needs, but a lack of shared vocabulary (Middleton et al. 2019) and the inability of stakeholders to clearly articulate desired environmental outcomes can present a barrier (Muñoz-Erickson et al. 2010). Visual aesthetics often determines how stakeholders perceive projects and potentially influence project success or failure (Arsénio et al. 2020). For example, during a large restoration project along the Thur River, Switzerland, scenic

beauty was the only factor that consistently predicted acceptance across all villages studied (Seidl & Stauffacher 2013).

Aesthetics are a commonly documented cultural ecosystem service (Hernández-Morcillo et al. 2013), but community members often have divergent preferences for how a landscape should look (Tveit et al. 2006). Nonetheless, few restoration projects outside urban landscapes have considered incorporating aesthetics that match the preferences of the local community (Arsenio et al., 2020). Several notable projects that aim to improve ecological conditions have faced pushbacks because of an undesirable change to the visual landscape from the perspective of local community members. River rewilding from the Vezins Dam removal in France faced significant community pushback predominantly because of both concern around loss of the aesthetic landscape and flood risk (Boucher & Hudson 2023). When restoration projects align with local aesthetic preferences, they are more likely to receive long-term community care (Shepherd 2004), which supports project success and permanence.

Heterogeneity in Restoration

Humans tend to homogenize natural landscapes through land-use practices (Doxa et al. 2012; Solar et al. 2015; Vellend et al. 2007), which can negatively impact conservation goals. For example, damming, pollution, erosion, and channelization have degraded and homogenized riparian ecosystems and in turn have reduced the establishment of flood-adapted plant communities (Fierke & Kauffman 2005). Restored habitats could often benefit from more heterogeneity of microhabitats and resource availability that increase ecosystem resilience and biodiversity (Larkin et al. 2016), key goals in most restoration projects (Gann et al. 2019).

Despite potential ecological benefits of heterogeneous habitats, some community members prefer more manicured habitats. Human desire for ordered landscapes (Kaplan & Kaplan 1989) can contrast with the ecological benefits of heterogeneity, as greater habitat heterogeneity does not necessarily align with visual preferences (Dronova 2017) and can even negatively impact them through perceived messiness (Zahawi et al. 2014). Nonetheless, the relationship between different types and amounts of habitat heterogeneity with visual aesthetics are not well understood and hence have been difficult to incorporate in landscape design (Junker & Buchecker 2008; Dronova 2017).

Environmental Aesthetics

Human landscape preferences are influenced by numerous visual concepts which are influenced by heterogeneity (Dronova 2017; Tveit et al. 2006). Whereas past research has demonstrated relationships between individual visual concepts and specific types of heterogeneity (Junker & Buchecker 2008; McCormick et al. 2015; Gundersen et al. 2017), no comprehensive study has evaluated multiple types of heterogeneity and their relationships to several visual concepts within the same landscape context. Several ecological studies find a positive relationship between both species diversity and resilience with five types of habitat heterogeneity (Carey 2003; Larkin et al. 2016; Carrasco et al. 2019; Table S1). Visual studies find these same measures of heterogeneity can relate to an increase in perceived naturalness but a decrease in perceived care by humans of a landscape. Understanding the relationship between heterogeneity and several visual concepts could help project managers predict social responses to specific landscape designs (Salter et al. 2009). Several river

restoration studies have found that increased geo-morphological complexity increases the appeal of a landscape to the public by enhancing its perceived naturalness (Junker & Buchecker 2008; McCormick et al. 2015), but these studies did not evaluate public perception of other visual concepts such as care, which could help inform restoration designs that are more socially accepted (Nassauer 1995).

Visual surveys often solicit the aesthetic judgment of participants with sets of images with real or manipulated photographs of various managed and wild habitats (e.g. Kaplan and Kaplan 1989, Han 2009, Buijs 2009, Sklenicka and Molnarova 2010). However, since heterogeneity effects are sensitive to scale, magnitude, and configuration, conventional visual surveys are less effective at evaluating heterogeneity preferences (Baer et al. 2016). Three dimensional (3D) computer-based surveys can represent complex landscape patterns, particularly when survey participants can change perspective interactively, which allows humans to derive more information from the scene (Chen & Xu 2016; Herbert & Chen 2015). This interactive component is important since subtle visual cues can substantially change human perception of landscapes (Nassauer 1995).

Computer visualization studies can provide more realistic visual assessments because they can (1) control the simulated environment to only change specific indicators to be tested in a survey, (2) derive the visuals from accurate data that are mappable, and (3) can operate at multiple spatial scales (Ode et al. 2009). Additionally, interactive features like user-adjusted slider bars provide a way for participants to see the result of changing a single characteristic of their planned landscape in real time

(Grêt-Regamey et al. 2013), and more effectively communicate tradeoffs across various environmental and social scenarios (Salter et al. 2009).

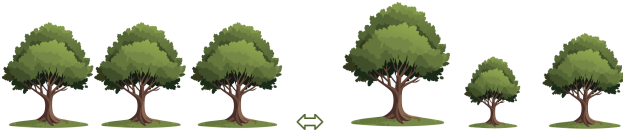
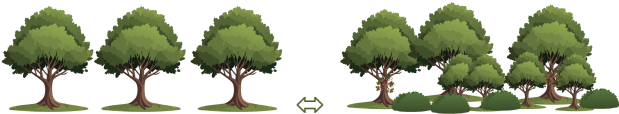
Aesthetics of Riparian Restoration

Riverine ecosystems are one of the most visually preferred ecosystems (Ode et al. 2009), but also have faced exceptional and continued degradation since early civilization (Palmer & Ruhi, 2019), which has led to significant losses to biodiversity and visual aesthetics (Bernhardt & Palmer 2007). This degradation has been particularly extensive in floodplains from land conversion to agriculture because of the fertile soil and relatively flat terrain. River and floodplain restoration requires improving visual aesthetics for social benefits (Cairns et al. 2024), and habitat heterogeneity for ecological benefits (Bernhardt & Palmer, 2007), but many restoration projects prioritize one or the other (Palmer et al. 2005; Junker & Buchecker 2008; Conniff 2014).

We created a visual survey for community members along the Sacramento River, the largest river in California, to study stakeholder perceptions and preferences for varying levels of heterogeneity across two measures of physical and three measures of vegetation heterogeneity (Table 1). This region is well suited to study heterogeneity preferences because the loss of about 95% of native riparian forests spurred large-scale floodplain restoration beginning in 1989, and over 3,300 hectares of riparian habitat have been restored since then (Golet et al. 2013). Still, this effort has primarily focused on horticultural planting rather than restoring natural processes, with less heterogeneity than naturally recruiting forests. However, visual messiness associated with the heterogeneity of restored landscapes relative to adjacent orchard lands have increased farm owner concerns that restoration could convey plant, bird, and insect

pests into farmland, and this perception ultimately reduces willingness to sell these lands for restoration (Buckley & Haddad 2006; Buckley & Crone 2008; Langridge 2010; Buckley & Holl 2011).

Table 1. Low and high variations of the types of heterogeneity studied.

Heterogeneity	Low Heterogeneity	High Heterogeneity
Topographic variability		
Tree clustering		
Tree size variability		
Understory complexity		
Large woody debris		

We aimed to determine whether visual preferences for riparian forest heterogeneity differ across biocentric (hiker, wildlife viewer) and utilitarian (fisher, hunter, farmer) stakeholder groups to understand how land use practices relate to landscape perceptions and the specific visual cues that drive this perception. Biocentric stakeholder groups primarily enjoy the intrinsic value of natural resources while utilitarian stakeholders focus more on practical benefits. Hence, we anticipated that biocentric participants would prefer higher levels of heterogeneity than utilitarian participants for all types studied (topographic, tree spacing, tree size variability, understory complexity, large woody debris), and that this preference would be closer to their definition of naturalness (Junker & Buchecker 2008). We predicted that utilitarian participants would prefer landscapes closer to their definition of cared for as prior work has suggested that interventions that show human care can make heterogeneity more attractive in rural communities (Nassauer 1995).

Methods

Study Region

The study area encompassed rural and urban communities along the entire 610-km reach of the Sacramento River. The region is characterized by a Mediterranean climate with warm, dry summers and mild, wet winters. The Sacramento River catchment includes the Cascade, Sierra Nevada, Klamath, and Coast Range Mountains and flows from the northern Central Valley to the San Francisco Bay-Delta. The hydrology and geomorphology of this river system are heavily influenced by both Shasta Dam and a network of levees that hydrologically disconnect floodplains along much of the river.

Riparian forests in this area typically feature valley oak woodland, mixed riparian forest, and oak savannah habitats. Typical restoration practices included disking and then planting a mix of native riparian forest trees and shrubs in rows (Alpert et al. 1999). These projects have received extensive state and federal funding with added support from several non-governmental organizations that fund habitat management and restoration (Golet et al. 2013). Restoration lands are commonly bought from farmers and then managed over the long-term by federal and state agencies.

Survey Technology and Design

We used interactive computer-generated 3D riparian forests in Unreal Engine v5.2 to survey participants' visual preferences by allowing users to select between two landscapes with differing levels of heterogeneity and to design their own preferred landscape (Figure 1a & b). All landscapes could be rotated and enlarged to provide multiple perspectives. All survey sessions were streamed from a dedicated server using Pixel Streaming v5.2, which standardized the visuals and allowed participants to connect via phone, tablet, or computer. To simulate riparian vegetation, we purchased 3D models for trees, shrubs, and grasses from the Unreal Marketplace and Artstation.com that looked similar to plant species along the Sacramento River. The final version of the survey incorporated feedback from several iterations of testing from pilot surveys, as well as from digital media and psychology researchers.



Figure 1. Examples of landscape selection and landscape design questions. The landscape selection question (a) shows two levels of tree size heterogeneity, on the left, (1) low heterogeneity shows even-sized trees, and on the right, (2) high heterogeneity shows variable-sized trees. The buttons on the bottom allow mobile users to control the perspective and show the option to select landscape 1, landscape 2, or no preference. The progress bar at the top shows the percentage of the survey remaining. The

landscape design question (b) allows the participant to rotate and zoom while changing heterogeneity levels in real time using interactive slider bars.

The landscape selection questions tested four types of heterogeneity—tree clustering, tree size, topographic variability, and understory complexity (Table 1, Figure 1a)—for four hypothetical young forests or field-measured tree location, stem diameter, and species data from four older riparian forests (Constantz et al. 2025). We asked participants to choose between pairs of low and high heterogeneity simulated riparian forests where one of the four types of heterogeneity was set to “high” in one forest simulation and “low” in the other, while the remaining three types remained constant to isolate the influence of a single factor on preference. High and low variants were generated using the R programming language (v4.4.0) (R Core Team 2022).

To simulate old forests, we increased or decreased the variation in field data for each type of heterogeneity by a factor of three except for tree size variability by a factor of two. We used the R programming language to generate variations of tree heterogeneity by creating several versions of tree location, species, and size, as comma-separated value files, which we read into Unreal Engine. For topographic variability, we modified the amplitude of the digital elevation map from the National Elevation Program (USGS 2022). For trees, we adjusted the coefficient of variation of tree size and nearest neighbor distance for tree clustering. We modified the mean understory cover for understory complexity.

We designed young riparian forests to mimic typical restoration plantings since we did not have field data for these forests. We used four distinct terrains to simulate topography on which restored and remnant riparian forests occur: oxbows, floodplains,

farms, and levee crowns. Tree clustering was based on row plantings (typical restoration method in this system) for low heterogeneity and planting in tree clusters for high heterogeneity designs. Tree size was represented by similarly-sized small stems for low heterogeneity or a mixture of both smaller and larger stems for high heterogeneity. Understory complexity varied in the density of herbaceous vegetation, vines, and shrubs, with low complexity having sparse vegetation to represent a mowed landscape and high complexity having dense vegetation that looks unmanaged.

The landscape design question allowed participants to use interactive slider bars to select their preferred level of the four heterogeneity types mentioned previously, plus large woody debris (Figure 1b). We did not include large woody debris in the landscape selection questions, as we lacked field data for simulations. Participants could adjust the slider bars to a value between 0 to 1, where higher values were more heterogenous.

Survey Questions

The survey targeted community members 18 years or older living within ~40 km of the Sacramento River and ran from July 2023 to May 2024. Institutional review board approval was obtained before the start of the survey (UCSC Study #: HS-FY2022-305). We recruited participants through listservs targeting farming, fishing, hunting, conservation, botany, and wildlife viewing in the Sacramento Valley and Sacramento–San Joaquin River Delta regions, farmers markets in Chico (using iPads for on-site completion), and word-of-mouth referrals. This resulted in 85 complete responses for the landscape selection portion of the questionnaire and 62 submissions for the landscape design question. To maintain the privacy and confidentiality of participants,

no personally identifiable information was collected (e.g. IP address, name, email, age, gender).

Demographic information collected at the start of the survey included participants' proximity to the Sacramento River and up to two primary uses of riparian landscapes. Land use categories were based on US Fish and Wildlife's classification (hunting, fishing, wildlife and plant viewing) with the addition of farming and habitat restoration. For preferred land uses (up to two selections), 15 selected farming, 12 selected hunting, 35 selected restoration, 27 selected fishing, and 69 selected plant and wildlife viewing. We did not have a sufficient sample size to subdivide user groups into individual land use categories for analysis, so we categorized land users as biocentric (i.e., consider the landscape to have value in-and-of itself) or utilitarian (i.e., consider the landscape to provide benefits for farming, hunting, or fishing). Based on participant selections, they were classified as biocentric if they only selected habitat restoration and/or plant viewing, or utilitarian if they selected fishing, hunting, or farming as one of their land uses; among utilitarian users 67.5% indicated fishing, 37.5% farming, and 30% hunting.

Our survey consisted of two main components: 50 paired-landscape selection questions and a single landscape design question (Figure 1). To evaluate how naturalness, stewardship, and complexity relate with heterogeneity, we asked 'What levels of heterogeneity make the landscape look most [natural, cared for, and complex]?'. To evaluate ideal levels of heterogeneity we asked, 'What levels of heterogeneity do you prefer?' We ultimately excluded the "disturbed" responses from our analysis as this concept proved problematic in riparian settings, which naturally experience flood disturbance. We also provided a "no preference" response for cases

when participants did not have a strong preference between high and low heterogeneity.

The survey had 160 possible questions (5 visual concepts $\times$ 8 forest landscapes $\times$ 4 heterogeneity variables). To manage survey length and fatigue while ensuring statistical validity, we randomly assigned 50 questions to each participant, maintaining even distribution across all visual concepts and landscapes. We removed all duplicate questions by retaining only the first unique combination of concept, landscape, and heterogeneity variable from each participant. For the landscape design question, we included responses only if participants had actively engaged with the interface by moving all sliders from their starting positions and formally submitted their completed design.

At the end of both the landscape and design selection portions of the survey, we invited participants to explain their decision-making process in an optional text response field. The analysis included 63 total written responses with relatively even distribution between the two participant categories (29 biocentric, 34 utilitarian). These qualitative responses helped supplement our quantitative findings by revealing factors that could drive group preferences.

Survey Analysis

We constructed separate Generalized Linear Models (GLMs) for each of the heterogeneity type as our independent variables and our stakeholder groups and visual concepts as our dependent variables. We used a group $\times$ visual concept interaction term and an estimated marginal means to test whether biocentric and utilitarian groups exhibited different probabilities of selecting high heterogeneity landscapes across visual

concepts. Our response variable was defined as a binary choice between high heterogeneity versus low heterogeneity, where “no preference” responses were removed, allowing us to employ the more statistically powerful binomial family rather than a multinomial approach. We applied a beta binomial distribution with a logit link for most models, as this appropriately handled individual-level proportions derived from varying numbers of questions per participant. For the tree clustering model, which failed to converge with the beta binomial distribution, we employed a standard binomial distribution. We evaluated model fit by checking dispersion and residuals using DHARMA diagnostics. We used a Student’s t-test to evaluate whether overall preference for heterogeneity values differed significantly from 0.5.

We analyzed written responses using thematic coding techniques to identify patterns across participant groups regarding their underlying motivations for landscape preferences. We employed a two-pass coding approach to reduce responses to common themes, first conducting open coding to identify initial concepts, followed by axial coding to establish relationships between themes (Gutmann 2014).

Results

Heterogeneity Preferences

Across all survey participants, respondents preferred high heterogeneity landscapes for tree size variability (Figure 2; $t = 6.2$, $p < 0.001$) and understory complexity ($t = 3.2$, $p = 0.002$) and had no consistent preference for topographic variability ($t = 1.8$, $p = 0.075$) or tree clustering ($t = -1.4$, $p = 0.179$). Participants had the highest frequency of selecting no preference for tree clustering ($20.0 \pm 4.5\%$) followed by topographic variability ($14.8 \pm 4.0\%$) (Figure S1).

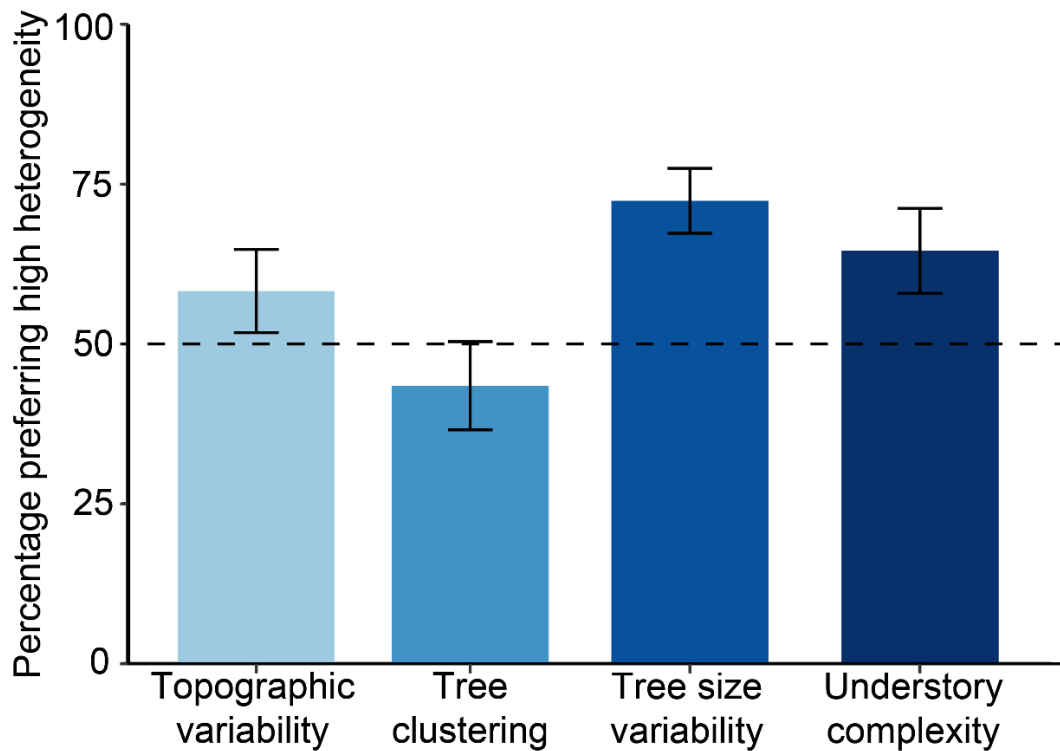


Figure 2. Mean percentage ($\pm$ SE) of selecting the high heterogeneity landscape for each heterogeneity type. Values represent the percentage of times participants chose high heterogeneity options, averaged across $n = 85$ participants. The dashed line shows a 50% chance of selecting high heterogeneity.

In the landscape selection (Figure 3a, Table S2), but not the landscape design question (Figure 4, Table S3), biocentric participants preferred significantly greater topographic heterogeneity than utilitarian participants. Both groups had similar preferences for tree clustering in both the landscape selection and design questions (Figure 3b & 4; Table S2). Biocentric participants preferred more tree size variability in the landscape selection questions and large woody debris when designing a landscape (Figure 3c & 4; Table S2). In both landscape selection and design questions, biocentric participants preferred more understory complexity than utilitarian participants (Figure 3d & 4).

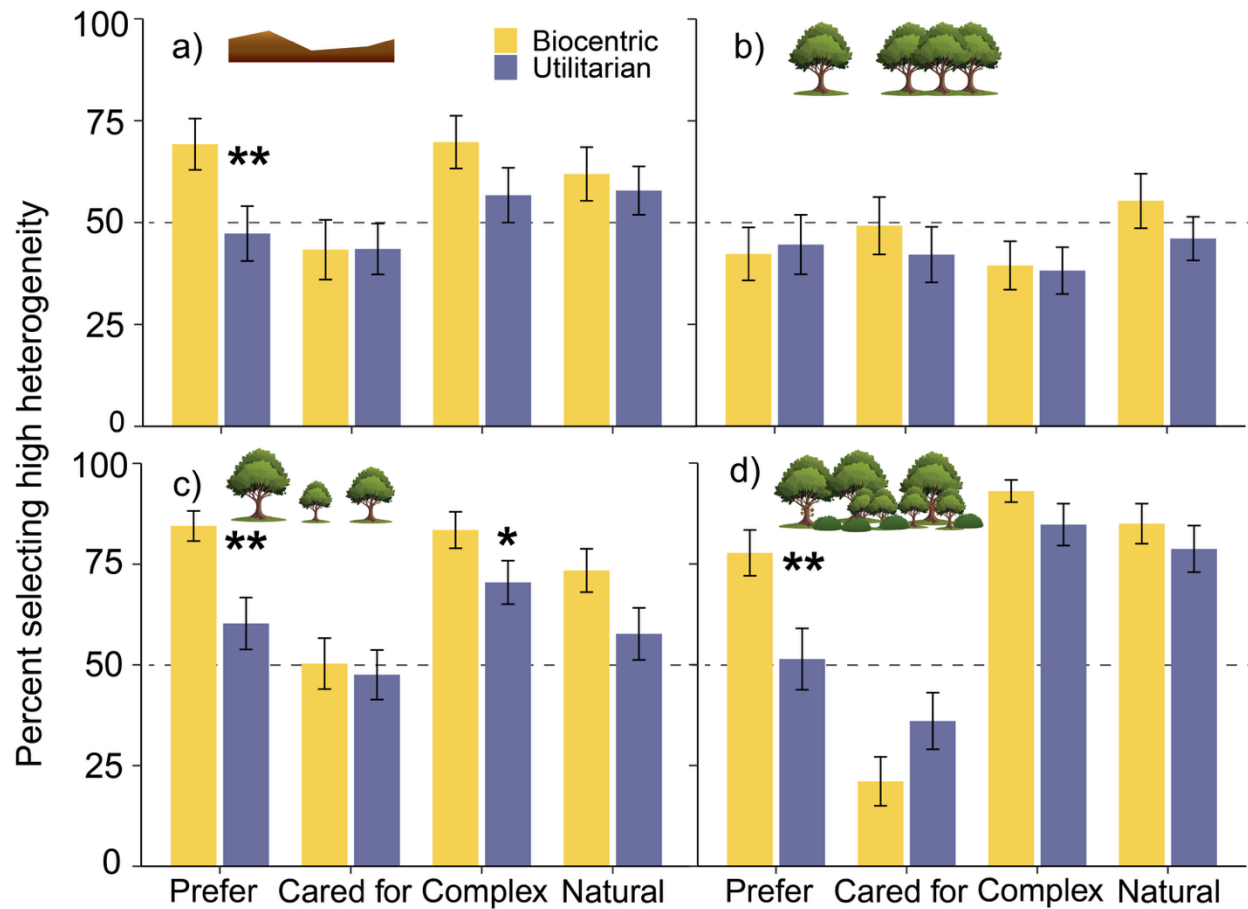


Figure 3. Mean percentage ($\pm$ SE) of selecting the high heterogeneity landscape for (a) topographic variability (b) tree clustering (c) tree size variability and (d) understory complexity for $n = 45$ biocentric and $n = 40$ utilitarian participants. Questions were framed as “Which landscape looks more [visual concept]?” where the visual concepts are listed on the x-axis. Full statistical contrasts are listed in Table S2. ** $p < 0.01$, * $p < 0.05$. The dashed line shows a 50% chance of selecting high heterogeneity.

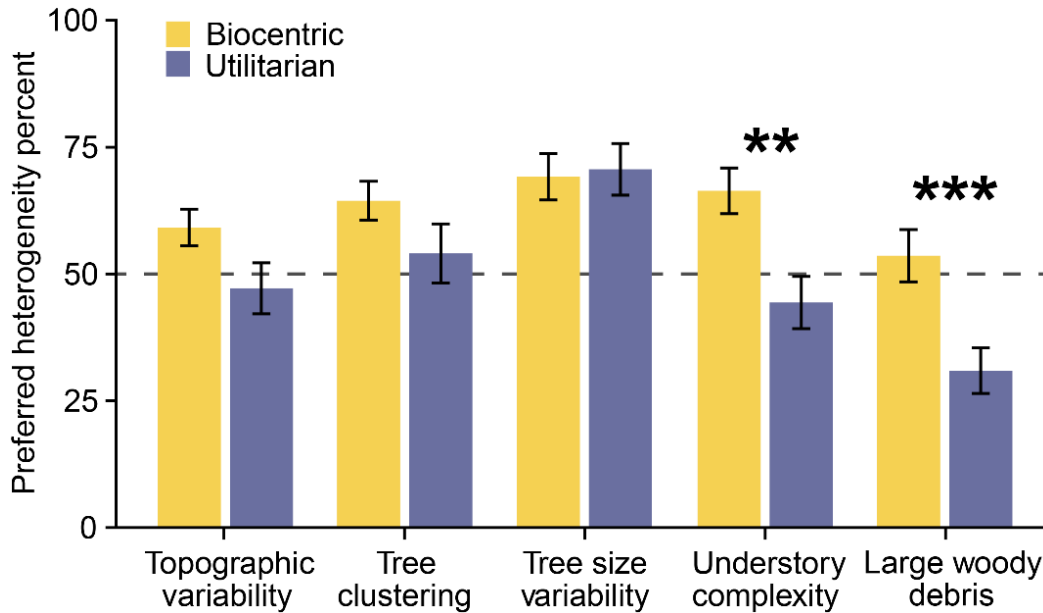


Figure 4. Mean preferred heterogeneity percent ($\pm$ SE) for each response variable by stakeholder category for biocentric ($n = 34$) and utilitarian participants ($n = 30$). Full statistical contrasts are listed in Table S3. *** $p < 0.001$, ** $p < 0.01$. The dashed line shows a 50% chance of selecting high heterogeneity.

Visual Concept Definitions and Motivations

Perceptions of which landscapes looked most natural and cared for did not differ significantly between stakeholder groups for any heterogeneity type (Table S2).

Utilitarian participants saw cared for landscapes as similar to their preferences for topography, tree size, and understory complexity, unlike biocentric individuals whose landscape preferences more closely matched with what they perceived as natural (Table 2). Biocentric participants perceived visually complex landscapes as having greater variability in tree size than utilitarian participants. Utilitarian participants indicated that visually complex and natural landscapes were both more heterogeneous than their preferences for understory complexity.

Plant diversity was one of the most commonly stated reasons driving landscape selection though it was cited much more frequently by biocentric (48.3%) than utilitarian (14.7%) participants. Other common reasons for selecting between landscapes stated by biocentric participants included large trees (48.3%), shade (17.2%), intermediate understory complexity (17.2%), dense understory (17.2%), and naturalness (17.2%). Utilitarian participants shared fewer reasons that influenced their decisions, but common justifications included landscapes with high mobility (17.6%), intermediate understory complexity (14.7%), and greater farming quality (11.8%).

Table 2. Estimated marginal means (z value) for the difference between a group's preference and their definition of cared for, complex, and natural for each heterogeneity type. A negative value indicates that respondents' definition of a visual concept is more homogenous than their preference. n = 45 for biocentric and n = 40 for utilitarian participants. *** p < 0.001, ** p < 0.01, * p < 0.05.

Heterogeneity type	Group	Cared for	Complex	Natural
Topographic variability	Biocentric	-1.18 (-3.14)**	-0.09 (-0.23)	-0.48 (-1.34)
	Utilitarian	-0.27 (-0.82)	0.41 (1.23)	0.29 (0.85)
Tree clustering	Biocentric	-0.08 (-0.23)	-0.34 (-1.03)	0.22 (0.66)
	Utilitarian	-0.24 (-0.71)	-0.14 (-0.42)	0.02 (0.05)
Tree size variability	Biocentric	-1.43 (-4.03)***	0.13 (0.32)	-0.62 (-1.67)
	Utilitarian	-0.55 (-1.64)	0.23 (0.71)	-0.09 (-0.27)
Understory complexity	Biocentric	-2.50 (-5.43)***	1.21 (2.28)	0.68 (1.41)
	Utilitarian	-0.53 (-1.31)	1.84 (3.82)***	1.17 (2.68)*

Discussion

Visual Perception of Riparian Landscapes

Both biocentric and utilitarian user groups preferred an intermediate level of heterogeneity and considered natural landscapes to be more heterogeneous than cared for landscapes. These similar visual perceptions across groups could in part stem from what Hull et al. (2001) describe as cultural naturalness where perceived naturalness comes from the landscape to which individuals became accustomed to seeing around them. In contrast, differences in preferences, such as biocentric participants preferring slightly more topographic variability, tree size variability, and understory complexity, could be explained by the distinct ways they relate to a landscape relative to utilitarian participants (Nassauer & Faust 1997; Eaton 1999).

Vegetation and topographic heterogeneity provide a physical structure that creates a visually rich landscape (Häfner et al. 2018), as well as ecological benefits (Dronova 2017). Varied tree heights and older trees in the landscape increase the visual appeal of riverside cities (Paletto et al. 2013; Chen & Xu 2016), and are the most influential factor when designing forest landscapes (Lindemann-Matthies et al. 2010), in part by making forests visually distinct from plantations (Sklenicka & Molnarova 2010; Gundersen et al. 2017). Both topographic and understory heterogeneity make landscapes less monotonous and more visually distinct, but the optimal amount of heterogeneity depends on the landscape (Arnberger & Eder 2011a; Angileri & Toccolini 1993). In our study, participants did not prefer high topographic variability or tree clustering, potentially because they can look messy or occlude visually rich elements

like the understory (Gundersen et al. 2017; Aminzadeh & Ghorashi 2007; Arnberger & Eder 2011a).

Several differences in preferences between biocentric and utilitarian stakeholders may relate to varying mobility needs. Utilitarian stakeholders preferred less large woody debris, simpler understories, and flatter terrain than biocentric participants, which likely relates to their desire to be able to easily move through the landscape, as hunting and fishing often require people to walk off trails to find wildlife. Despite dense understories being visually appealing (Polat & Akay 2015), previous studies concur that people often prefer sparse understories when needing to walk through a landscape (Gundersen et al. 2017; Arnberger & Eder 2011b). Moreover, prior research shows that participants can accurately perceive landscapes with more conservation value but visually prefer landscapes with more recreational value (Dramstad et al. 2001; Aminzadeh & Ghorashi 2007). Biocentric participants in our study, mostly do activities that allow them to stay on the trail, and preferred landscapes that were more visually complex. This higher visual complexity would unlikely impede their movement and would enhance the scenic beauty and “naturalness” by increasing the plants, wildlife, and other visual elements they appreciate (Bartha et al. 2006; Junker & Buchecker 2008; Lindemann-Matthies et al. 2010), and are missing in an orderly landscape like urban parks.

Both participant groups, who all lived near the Sacramento River, visually defined both cared for and natural landscapes similarly. Both perception of naturalness (van Zanten et al. 2016; Piégay et al. 2005; Gundersen et al. 2017), and care are influenced by proximity to a landscape (Nassauer 1995; Hull et al. 2001). Both Sheppard (2001) and Lindemann-Matthies et al. (2010) describe preferred landscapes as a balance

between naturalness and care. Nonetheless we found each group preferred opposite ends of this spectrum rather than a blend, such that utilitarian participants preferred landscapes that looked cared for while biocentric participants preferred landscapes that looked more natural. This results is consistent with other studies suggesting that relationship to the land often better explains preference differences than differences in visual concept definitions (e.g. naturalness vs. cared for) (Gobster 1999; McCormick et al. 2015; Sklenicka & Molnarova 2010).

Interactive Visual Surveys—strengths, limitations, and lessons learned

Our 3D interactive visual survey illustrates that some restoration projects, particularly those where there is planned human recreational usage, could benefit from this approach. By being able to simulate real data, this survey platform can test multiple dimensions of a landscape individually. Rather than providing a fixed perspective, which can undermine transparency and stakeholder engagement (Downes & Lange 2015), our approach gives the participant the ability to control perspective, which may have also contributed to perception of subtle environmental differences. Using interactive visual surveys could provide new modes to interface between restoration planning teams and the public on environmental projects, architectural designs can be parsed into mappable data for game engines to make a similar survey.

A few limitations of our visual survey suggest it might not be feasible or appropriate for certain stakeholder engagements and provide insights for future similar surveys. First, the survey was resource intensive to create and deploy, taking hundreds of hours to develop conceptually and programmatically. However, this software approach could be automated so future projects would only need to input their terrain,

vegetation models, and restoration designs to produce a new visual survey, which would take less time. This approach could include landscape restoration in highly trafficked areas in or near cities, where multiple visual preferences may need reconciliation (Gobster et al. 2007). Manipulating photographs of real landscapes and hosting the survey on a more standard survey platform, like Qualtrics, might provide useful feedback without the challenges of an interactive survey. Second, the lack of difference between groups' preferences for tree clustering may have been due to an actual lack of preference or due to an inability to distinguish low and high versions of this feature in our survey, given that this variable had the highest rate of "no preference" responses. The depiction of tree clustering could be improved in a subsequent survey.

Finally, additional survey participants would have strengthened our statistical power and further separated land user groups, but recruiting participants was challenging. Some people had issues connecting to the survey or lacked the computer knowledge to be able to complete the survey. We found that allowing people to complete the survey in a public setting (e.g., a farmers' market) with verbal instructions from a research team member facilitated participation, so we recommend this approach for future similar surveys.

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None of the code used in this study is novel. All statistical analyses were performed using functions from publicly available R libraries, which are all cited within the manuscript. All raw data and statistical code in the R programming language (v4.4.0) that reproduce every statistical table and figure used in our results and appendix is published at <https://doi.org/10.5281/zenodo.18236747>.

During the preparation of this manuscript the first author used Claude solely to provide feedback on grammar and flow of specific text. No content was generated or altered by AI tools, and the authors take full responsibility for the content of the published article.

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