Title: General attributes and practice of ecological restoration in Arizona and California, USA revealed by restoration stakeholder surveys

RUNNING HEAD: **Restoration in Arizona and California**

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AUTHOR CONTRIBUTIONS: ESG developed and conducted the surveys and collected the data; YML analyzed the data and performed statistical analyses; ESG, YML developed the manuscript.

ABSTRACT

Ecological restoration has become increasingly important in conservation. Yet, synthesized statistics are scarce with respect to essential characteristics of restoration activities. We surveyed restoration stakeholders in the U.S. states of Arizona and California to evaluate key attributes in restoration activities including ecosystems of focus, goals, size, cost, duration, and the prevalence of recommended restoration practices. We also examined how some of the attributes varied with size of restoration, ecosystem type, and state identity. While enhancing biodiversity and increasing plant cover were common goals in the two states, restoration in California also focused more on wildlife habitat re-establishment and weed control. Restoration in Arizona was implemented more in arid/semiarid systems, larger in size, shorter in duration, used more passive restoration, spent more on equipment, and was less likely to source plants from native plant nurseries. Labor was the most expensive restoration component regardless of state identity and ecosystem type. Per unit area cost of restoration decreased with increasing size of restoration. Yet, the decline in this cost was more strongly explained by moving from mesic to arid/semiarid ecosystems. Duration of restoration projects increased with size of restoration and in more mesic ecosystems. Overall, restoration in mesic ecosystems, compared to arid/semiarid systems, was smaller in size, higher in cost, and longer in duration. These results confirmed that ecological and socio-political conditions impact restoration goals and practice, with implications of how research can further support practitioners to achieve restoration success under practical constraints revealed by these results.

KEYWORDS: restoration survey, restoration cost, scale dependency, restoration duration, restoration practice

IMPLICATIONS FOR PRACTICE

- Although most common types of ecosystems for restoration may vary with climate, mesic systems such as riparian habitat receives high priority even in an arid state like Arizona.
- While enhancing biodiversity is a common goal for restoration, holistic restoration design may meet often diverse and interdependent goals coming from different socio-political interests.
- Restoration projects in mesic systems are often more expensive and last longer than those in arid/semiarid systems, suggesting a need for increasing cost-effectiveness.
- Restoration in Arizona needs more support to enhance post-restoration monitoring, to increase the procurement of native plant materials from native nurseries, and to reduce equipment cost, perhaps through the creation of restoration cooperatives for resource sharing.

INTRODUCTION

Rapid changes in climate, spread of non-native species, and industrial urbanization are elevating the need for effective ecological restoration across regional landscapes. Developing restoration strategies effective across space and time requires understanding what drives the variation in restoration success (Esler et al. 2010; Anderson 2014). Some of these drivers are ecological and are related to, for example, local ecological dynamics (Kimball et al. 2015; Anderson et al. 2006) and site specific conditions (Kimball et al. 2015; Pavao-Zuckerman 2008). Other drivers are practical elements in restoration design, such as the cost of restoration (Kimball et al. 2015; Holl & Howarth 2000) and the use of a relevant reference site (White & Walker 1997).

Despite the recognition of the value of these drivers, restoration researchers and practitioners have thus far known very little, on a broad scale, how these factors have been considered and incorporated into restoration practice and how they vary across restoration sites. This is likely due to the fact that researchers, who are primarily responsible for publishing this type of information (McKinley et al. 2012), typically have little access to data about the prevalence of critical practices recommended for restoration (Clark et al. 2019). The absence of formally collected and published information about practical aspects of ecological restoration creates a substantial gap between restoration research and practice, slowing down the overall progress of ecological restoration.

Closing this gap implies that both researchers and practitioners need access to critical information such as types of ecosystems most in need of restoration, the main goals of restoration, and the spatial scales on which restoration projects take place (Clewell & Rieger 1997). Costs and durations of restoration are critical components to consider for developing

73 practical approaches that can meet practitioners' financial and administrative constraints (Holl &
74 Howarth 2000).
75 Equally important is to understand how important restoration attributes change due to
76 variation in environmental and socio-political conditions. For example, restoration goals,
77 strategies, and constraints across ownership types or political boundaries can differ greatly
78 because stakeholders often have dissimilar values, priorities, and perceptions of restoration
79 success (Hagger et al. 2017; Bernhardt et al. 2007; Aggestam 2014; Clark et al. 2019). Despite
80 this difference, diverse restoration goals and strategies are often interdependent and therefore can
81 be addressed in a well-planned restoration project under the holistic design principle (Naveh
82 2007; Hagger et al. 2017).
83 Cost, cost effectiveness, and duration of restoration projects can change with the spatial
84 scale of restoration and the types of ecosystems (Kimball et al. 2015; Powell et al. 2017; Turner
85 & Boyer 1997). Per unit area cost usually declines with increasing restoration size likely due to
86 the reduced per unit area establishment cost in larger restoration projects (Powell et al. 2017).
87 However, the opposite could also be found (Turner & Boyer 1997). More mesic and more
88 productive ecosystems can experience higher intensity of competition between desirable and
89 undesirable plant species or more severe habitat degradation due to human activities. Therefore,
90 these systems may require more active restoration and, thus, higher cost for achieving restoration
91 success (Palma & Laurance 2015; Dorrough et al. 2008, 200; Rodrigues et al. 2011). Yet, it is
92 unclear how prevalent these differences are.
93 Given the aforementioned information gap, the general goal of this study was to
94 synthesize essential attributes of restoration (e.g., size, cost, and duration) and practice of
95 restoration (e.g., the use of a reference site) and then to infer factors responsible for the variation

96 in these synthesized restoration features. To do so, we surveyed more than 200 restoration
97 stakeholders in the U.S. states of Arizona and California. We analyzed survey responses to
98 determine the most common types of ecosystems for restoration, common goals in restoration,
99 and the spatial scale, cost, and duration of restoration projects. We also evaluated the prevalence
100 of critical practices in restoration: the use a reference site, the use of passive restoration, the use
101 of native plants, and the implementation of post-restoration monitoring.
102 Furthermore, we asked how most of these attributes changed with the identity of state
103 (Arizona vs. California), the size of restoration projects, and the aridity of the ecosystem of
104 focus. California is larger, comprised of a greater latitudinal gradient and more types of
105 ecosystems, and is more mesic than Arizona. California also has a more developed commercial
106 restoration industry (as suggested by the Society of Ecological Restoration directory). The state
107 implements some of the most progressive environmental regulations and policies in the U.S.
108 (Presley 2011; Vasey & Holl 2007; Barbour & Kueppers 2012) and a carbon cap-and-trade
109 program (Matzek et al. 2015), which may incentivize certain restoration practices and perhaps
110 even larger restoration projects. These interstate differences in environmental and socio-political
111 conditions make the comparison between these two states relevant to other geographic regions
112 with similar variation in these conditions.
113 Overall, we used survey responses to assess 1) how ecosystems for restoration,
114 restoration goals, area size of restoration projects, and the most expensive component in
115 restoration differed between states and between arid/semiarid vs. mesic ecosystems; 2) how
116 restoration cost, duration, length of post-restoration monitoring, and percent time spent on
117 passive restoration varied with size of restoration, state identity, and the aridity of ecosystems;
118 and 3) how critical practice in restoration, including the use of reference sites, the use of native

plants, the sourcing of plant materials, and the implementation of post-restoration monitoring varied with the size of restoration, state identity, and the aridity of ecosystems.

METHODS

Surveys

Two original surveys were developed for the state of California and Arizona, respectively (surveys available at https://osf.io/cvf2d/; DOI: 10.17605/OSF.IO/CVF2D). These two surveys shared sixteen questions in common (Table 1), which were analyzed and compared in this study. These questions were designed to understand survey participants' professional background, essential aspects of restoration practices, and the needs of restoration practitioners.

Surveys in California were conducted in 2016 and those in Arizona, in 2018. The study was approved by the Institutional Review Board protocol 784586-1. Overall, survey participants included individuals involved in restoration design, deployment, management, and monitoring. Surveys were distributed in two ways in order to enhance response from individuals most involved in restoration in each state: distribution during restoration focused meetings and direct contact with practitioners who did not attend those meetings.

Surveys were first distributed in each state to all attendees at local plant (mostly grassland) restoration focused meetings organized by one of the authors (ESG). In California, meetings included 'Do No Harm' on the University of California, Davis campus (November 2016) and the annual meeting of the California Society for Ecological Restoration in North Lake Tahoe (May 2016). In Arizona, meetings included the Madrean Conference in Tucson (May 2018) and the annual meeting of the Society for Ecological Restoration Southwest Chapter in Flagstaff (September 2018). Attendees at these meetings were a mix of mostly land managers, practitioners, and academics who were involved in ecological restoration and were self-selecting

to attend the meetings. Potential respondents were informed that the survey was anonymous and that participation was voluntary. Although attendance at multiple meetings where the survey was distributed was unlikely (meetings tended to be region-specific), participants were asked to not take the survey if they had already done so at another meeting.

Meeting attendees were provided with a paper survey with the 2004 Society of Ecological Restoration definition of restoration (*restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed*) at the top of the survey. Survey question types included scaled, multiple choice, and open ended (Table 1). Respondents provided the completed survey to the meeting registration table at their leisure. Response rate varied by meetings. It averaged 69% of the 149 distributed surveys in Arizona and 63% of the 106 distributed surveys in California.

Key practitioners in each state who were known to not attend the meetings in which the surveys were distributed were emailed directly by ESG and provided a link to an online survey. Key practitioners were identified in two ways. First, well known restoration practitioner organizations and conservation managers were identified through established connections via Cooperative Extension in each state. Second, we used a snowball sampling technique (e.g., Biernacki & Waldorf 1981) where each individual who was initially contacted was asked to suggest other individuals who would be appropriate for the survey. We emailed 31 practitioners in California, of which two responded (a response rate of 6.5%). We also emailed 361 practitioners in Arizona and other non-California states and 79 of them responded (a response rate of 21.9%), of which 57 were from Arizona.

We manually validated all survey responses and eliminated apparent errors. The number of responses to each question varied and is noted throughout this article as either sample sizes or degrees of freedom of linear models.

Analyzing survey responses

Statistical analyses of organized survey data were performed in R version 3.6.3 (R Core Team 2020). R script and the data are available at https://osf.io/cvf2d/ (DOI: 10.17605/OSF.IO/CVF2D). Responses to the survey questions fell into three general categories of variables: continuous numeric variables, Likert-scale variables, and categorical variables (Table 1).

All but one of the continuous numeric variables approached log-normal distributions more strongly than normal distributions, reflecting that all these numeric responses had a floor of zero and a long-tail created by a small number of extreme positive values. These variables (size of restoration, per unit area cost of restoration, duration of restoration, and duration of post-restoration monitoring) were $\log_{10}$ transformed and were analyzed statistically on this logarithmic scale (Table 1). The variable "percent time passive restoration was employed" resembled neither a normal nor a log-normal distribution. This variable was analyzed on an arithmetic scale (Table 1). Some of the responses gave either a minimum or maximum value (e.g., size < 5 acres) or both the lower and upper bound of a value range (e.g., restoration duration between 1 and 15 years). If only a minimum or maximum value was given, that boundary value was used. If both the lower and upper bound were given, the midpoint of the two bounds was used. In the case of responses to questions 4, 5, 7, and 9 (Table 1), the midpoint was calculated on a logarithmic scale.

185 The Likert-scale variables (frequency of post-restoration monitoring and that of using a
186 reference site; Table 1) were converted to a scale of -2 to 2, where 0 indicates a neutral answer to
187 each question (a restoration project was "sometimes" monitored or a reference site was
188 "sometimes" used), -2 indicates the most negative answer to each question (a restoration project
189 was "never" monitored or a reference site was "never" used), and 2 indicates the most positive
190 answer to the question.
191 After transformation of the aforementioned variables, the general linear model (*lm*
192 function in R) was used to evaluate whether the size of restoration differed between the two
193 states, and whether the rest of the numeric and Likert-scale variables were significantly
194 influenced by state and the size of restoration. The interaction between state and the size of
195 restoration was not included in any model because the inference of this interaction would not be
196 reliable given the strong sample size imbalance between the two states (Hector et al. 2010). State
197 and the size of restoration were correlated (see Results). Therefore, we used both forward and
198 backward AIC-based stepwise regression (*stepAIC* function in R) to select the best model for
199 each response variable. An AIC-based approach was appropriate for comparing the reduced
200 models (each with only one of the two independent variables), which were not nested (Murtaugh
201 2014). In results, we reported classic statistics (F statistic, p value, etc.) of each selected model
202 for the purpose of conventionality.
203 For the categorical variables (organization, occupation, ecosystem for restoration,
204 restoration goal, source of plant materials, and having a formal policy of using only native
205 plants; Table 1), we calculated the percentage of responses that fell into each category. Multiple
206 categories could be chosen in a response (except for answers to whether or not having a formal
207 policy of using only native plants). Therefore, the percentages of all categories in a question did

not always sum to one. When analyzing responses with regard to participant occupation (Table 1), we created a "researcher" category to include any answer of "academic researcher" and any write-in response that indicated a non-academic research position. When analyzing responses with regard to the most expensive component of a restoration project (Table 1), we created two new categories: "construction" and "permitting". The construction category included write-in answers such as grading, dirt work, engineering, and fencing. The permitting category included write-in answers such as permitting, National Environmental Protection Act compliance, and archeological surveys.

We used proportion tests (*prop.test* function in R) to evaluate whether the proportion of responses in each major category differed between the two states. Since each survey participant could choose multiple categories in each question (except for question 13; see Table 1), selecting one category does not directly affect the chance of selecting another category, implying that the proportional test on all categories in a question could be carried out independently of each other.

The general linear model and proportion tests were further used to examine whether the response variables differed between mesic and arid/semiarid terrestrial ecosystems where restoration took place. We created an explanatory variable of ecosystem type with two levels: mesic vs. arid/semiarid. We assigned responses that only reported "streams/rivers", "riparian", "wetland", "montane meadows", "forest", or any combination of these systems (question 3 in Table 1) to the mesic group; and those that only reported "grassland/rangeland", "desert", or any combination of the two to the arid/semiarid group. We then applied aforementioned statistical tests on response variables (except restoration ecosystems) against the ecosystem type.

Survey responses that fell into these two ecosystem types (n = 122) were a much reduced set than the full dataset (n = 229) and were highly imbalanced between the two states. Sample

231 sizes of each response variable could be even lower and more imbalanced since not all survey
232 responses provided answers that could give the response variable. We, therefore, did not analyze
233 the joint influence of state, size of restoration, and ecosystem type in our linear models under the
234 concern of insufficient statistical power. We acknowledged that the inference of the effects of
235 ecosystem type could be confounded by the effects of state and size of restoration (see
236 Discussion).
237 We chose not to control family-wise error rate due to the controversy around the
238 necessity of this control (Cox 1965; Stewart-Oaten 1995; Hurlbert & Lombardi 2012).
239 Specifically, the assumption that all null hypotheses in each of our tests would simultaneously be
240 true is overly restrictive and unlikely. We emphasized the reporting of both *p* values and effect
241 sizes (β, R^2, and the difference between proportions) to provide readers sufficient information
242 about the practical significance of the results.

243 # RESULTS

244 ## Survey participant background

245 Sample size of survey respondents were 160 in Arizona and 69 in California. Among them,
246 government agency employees had the highest representation in both states (41.9% in Arizona
247 and 39.1% in California, Fig 1a). University and NGO held equally the second highest
248 representation (23.8%) among survey participants in Arizona, whereas private business sector
249 had the second highest representation (30.4%) in California (Fig 1a). The most popular
250 occupation indicated by participants in Arizona was researcher (35.2%), followed by land
251 manager (32.1%); whereas in California, it was restoration practitioner (64.7%), followed by
252 land manager (20.6%) (Fig 1b).

Given the high ratio of self-identified researchers in the survey, we performed further analysis to assess whether responses by researchers differed from those by non-researchers (Supplement S1). There were marginally higher proportion of non-researchers reported "coastal" and "wetland" as their main ecosystems for restoration, and significantly higher proportion of researchers reported "forest" as their focal systems (Table S2). In addition, there were significantly higher proportion of non-researchers reported "weed control" as the most expensive component in restoration projects (Table S2). Given that only few differences existed between these two occupational groups, we chose to report results from analyses where data from these two groups were pooled.

Types of ecosystem for restoration and restoration goals

The most common type of ecosystem of restoration reported by survey responses was grassland in Arizona (50.6% of the 156 responses) and riparian in California (58.8% of the 68 responses) (Fig 1c). Restoration of grasslands, wetlands, and coastal areas all exceeded 30% of the responses in California; whereas restoration of riparian areas and desert exceeded or approached 30% of the responses in Arizona (Fig 1c). Urban restoration received noticeable attention in both states (12.8% and 22.1% of the responses in Arizona and California, respectively; Fig 1c). On the contrary, cropland restoration was relatively rare (6.4% and 5.9% of responses in Arizona and California, respectively; Fig 1c). Significantly higher proportion of responses from California indicated wetlands, riparian zones, and coastal zones as the most common ecosystems for restoration (wetlands: $\chi^2_1 = 37.299$, $p = 10^{-9}$; riparian: $\chi^2_1 = 12.345$, $p = 0.0004$; coastal: $\chi^2_1 = 52.374$, $p < 10^{-13}$), whereas desert was reported significantly more frequently in Arizona ($\chi^2_1 = 6.734$, $p = 0.0009$).

Enhancing biodiversity was the most mentioned restoration goal in Arizona (45.2% of the 135 responses), followed by erosion control (31.9%) and providing plant cover (31.1%) (left panel in Fig 2a). In California, providing wildlife habitat was the most mentioned goal (53.8% of the 65 responses), followed by weed control (41.5%), enhancing biodiversity (40.0%), and providing plant cover (35.4%) (left panel in Fig 2a). A significantly higher proportion of respondents in California listed providing wildlife habitat ($\chi^2_1 = 9.2909$, $p = 0.002$) and weed control ($\chi^2_1 = 12.771$, $p = 0.0004$) as the top restoration goals than did respondents in Arizona. The proportion of each restoration goal reported in the survey did not differ significantly between mesic and arid/semiarid ecosystems (p values of the proportional tests ranged from 0.084 to 1, right panel in Fig 2a).

Spatial scale, cost and duration of restoration projects

The reported size of restoration projects ranged from 0.1 to 2,306,758 hectares in Arizona (n = 132) and from 0.04 to 850 hectares in California (n = 58). The mean in Arizona and California, evaluated on a logarithmic scale, were 48.7 and 7.2 hectares, respectively. This interstate difference was significant (Table 2). Further, size of restoration projects in arid/semiarid systems was significantly larger than that in mesic systems (Table 3).

The reported cost of restoration ranged from 0.43 to 247,101 US Dollars per hectare in Arizona (n = 75) and from 0.86 to 989 US Dollars per hectare in California (n = 27). The mean cost on a logarithmic scale were $36.03 and $28.28 per hectare in Arizona and California, respectively. The variation in per hectare restoration cost was not explained by states, but rather by the size of restoration (Table 2) and the ecosystem type (Table 3). This per unit area cost declined significantly with increasing restoration size (Table 2, Fig 3a), and in arid/semiarid ecosystems as compared to mesic systems (Table 3, Fig 3a). The modeled log-scale linear

298 relationship between per unit area cost and restoration size, though significantly negative, was
299 not strongly linear (Fig 3a) and could only explain 4.9% of the variation in the cost (R^2 in Table
300 2). In comparison, the difference between arid/semiarid and mesic ecosystems explained 22% of
301 the variation in the per unit area cost (R^2 in Table 3).

302 Labor cost was most frequently reported in both states and in both ecosystem types as the
303 most expensive component of restoration projects (Fig 2b). The second most frequently reported
304 component was equipment in Arizona, weed control in California, and equipment in both
305 ecosystem types (Fig 2b). Among these most expensive components, weed control was reported
306 marginally more frequently in California than in Arizona ($\chi^2_1 = 3.744$, $p = 0.053$, left panel in Fig
307 2b); equipment, significantly more frequently in Arizona than in California ($\chi^2_1 = 13.337$, $p =$
308 0.0003, left panel in Fig 2b); and construction, significantly more frequently in mesic than in
309 arid/semiarid systems ($\chi^2_1 = 4.113$, $p = 0.043$, right panel in Fig 2b).

310 Restoration project duration increased significantly with size of restoration projects and
311 lasted significantly longer in California (Table 2, Fig 3b; see also Table S3). Project duration was
312 significantly longer in mesic systems than in arid/semiarid systems (Table 3, Fig 3b).

313 **Restoration practices**

314 The intercept of the responses to the Likert-scale question "how often do you use a reference
315 site" was significantly above the neutral point of "sometimes" (Table 2), suggesting that it was a
316 regular practice to use reference site for assessing the outcome of restoration. The Likert-scale
317 score of using a reference site did not change significantly with size, state, or the type of
318 ecosystems (Table 2, 3).

319 Percent time in which passive restoration was employed was significantly higher in
320 Arizona than in California (Table 2, Fig 3d; see also Table S3). The variation in this variable was

not explained by the change in size of restoration projects (Table 2), nor by the ecosystem type (Table 3).

Having a formal policy of using only native species for restoration was reported by 93 of the 133 (69.9%) responses in Arizona, 36 of the 63 (57.1%) responses in California, 32 of the 46 (69.6%) responses in mesic systems, and 45 of the 66 (68.2%) responses in arid/semiarid systems. The frequency of having this policy did not differ significantly between the two states ($\chi^2_1 = 2.562$, $p = 0.109$) or between arid/semiarid and mesic ecosystems ($\chi^2_1 = 0$, $p = 1$).

Native nurseries and field collection were respectively the first and second most frequently reported source for acquiring restoration plant materials in both states (left panel in Fig 2c). Native nurseries ($\chi^2_1 = 17.719$, $p < 0.0001$) and field collection ($\chi^2_1 = 8.0407$, $p = 0.0046$) were significantly more frequently reported as a source in California, whereas conventional nurseries ($\chi^2_1 = 4.671$, $p = 0.0307$) was reported significantly more frequently as a source in Arizona (left panel in Fig 2c). Field collection was more frequently reported as a source in mesic than in arid/semiarid systems ($\chi^2_1 = 13.701$, $p = 0.0002$, right panel in Fig 2c).

The intercept of the Likert-scale responses to the question "how often do you monitor a restoration project after it is completed" was significantly above the neutral point of "sometimes" (Table 2), suggesting that post-restoration monitoring was regularly practiced in both states. The variation in the Likert-scale score of post-restoration monitoring was not significantly explained by the size of restoration, the state identity (Table 2), or by the ecosystem types (Table 3).

Mean duration of post-restoration monitoring, on a logarithmic scale, was 3.7 years in Arizona, significantly lower than a mean of 5.1 years in California (Table 2, Fig 3c; see also Table S3). The size of restoration and ecosystem types did not significantly explain the variation in the duration of post-restoration monitoring (Table 2 and 3, Fig 3c).

DISCUSSION

Our survey captured responses from restoration stakeholders representing four major types of organizations (government agencies, universities, NGOs, and private business) and a diverse set of occupations. Their responses showed that while restoration projects in Arizona and California converged on common restoration goals including enhancing biodiversity and increasing plant cover, they diverged on other goals likely due to ecological and socio-political differences between the states. While restoration in riparian habitat captured substantial attention in both states, restoration in arid/semiarid system was more common in Arizona, whereas restoration in mesic systems was more common in California. This difference was likely due to the interstate climatic difference. The size of restoration and ecosystem type were both factors influencing the cost and duration of restoration projects. Yet, as indicated by small R^2 values, a large amount of the variation in restoration cost and duration were attributed to factors not identified in this study.

The prevalence of grassland/rangeland as a focus for restoration likely reflected the dominance of this ecosystem type in both states (McClaran & Brady 1994; Mooney & Zavaleta 2016) as well as a sampling bias as surveys were distributed in meetings mostly focusing on grassland restoration. Riparian restoration received high attention in both states and wetlands received high attention in California. The prevalence of restoration of mesic ecosystems in these two states, which are dominated by arid and semiarid climate, highlights the importance of these ecosystems. Humans value strongly mesic environments for their high productivity and biodiversity (Burmil et al. 1999). These systems, however, are some of the most vulnerable to land use change (Vörösmarty et al. 2010; Davis et al. 2015), biological invasions (Foxcroft et al. 2007; Richardson et al. 2007), and climate change (Perry et al. 2012). More research can be directed to mesic ecosystems to support the current and future restoration endeavor.

Practitioners in both states indicated a wide array of restoration goals. Enhancing biodiversity captured strong attention in both states, likely reflecting the increasing concern of the loss of biodiversity in this era of Anthropocene (Johnson et al. 2017) as well as an understanding of the relationship between biodiversity and ecosystem service provision (Rey Benayas et al. 2009). Enhancing biodiversity was also shown as the most common motivation of restoration in Australia (Hagger et al. 2017), suggesting the global attention to this endeavor. Interests in wildlife habitat re-establishment and weed control were significantly stronger among restoration projects in California than in Arizona. This difference might result from the implementation of state legislation that incentivized wildlife habitat restoration (Presley 2011), certain increase in funding for habitat restoration associated with the legislation (Barbour & Kueppers 2012), and greater pressure of plant invasion in the state of California (Stohlgren et al. 2003; van Kleunen et al. 2015). In this case, variation in ecological and socio-political conditions may lead to the divergence of restoration goals (Hagger et al. 2017; Bernhardt et al. 2007).

Many of the restoration goals reported in the survey are connected. Providing wildlife habitat usually requires enhancing biodiversity, which may, in turn, require weed control as invasive plants negatively impact native biodiversity (Gilbert & Levine 2013). Enhanced biodiversity can lead to greater ecosystem stability in a fluctuating environment (Tilman et al. 2014), which can fulfill several other restoration goals including increasing plant cover, reducing soil erosion, and enhancing water filtration in the long term (Rey Benayas et al. 2009). All these goals are frequently considered by restoration practitioners, underscoring the need of restoration plans and methods that can holistically address the root cause of ecological degradation and regenerate a system that can provide a multitude of ecological, socioeconomic, and cultural functions (Hagger et al. 2017; Naveh 2007; Ferwerda 2015; Velázquez-Rosas et al. 2018). This

type of holistic design can achieve multiple interdependent restoration goals, strengthen socio-political support of restoration, conserving resources, and ensuring long-term success. For example, watershed restoration on the Chinese Loess Plateau used a holistic design approach that achieved the goals of restoring vegetation cover, increasing vegetation diversity, reducing soil erosion, increasing soil health, and increasing long-term farm yields (Ferwerda 2015).

The size, cost, and duration of restoration projects are often subject to the financial, administrative, and ecological constraints faced by practitioners (Kimball et al. 2015). The findings that restoration projects were larger in size in Arizona and in arid/semiarid ecosystems were most likely dependent because arid/semiarid ecosystems were reported more frequently in Arizona than in California. We did not have sufficient sample size to evaluate the degree of this interdependence. Future studies can specifically compare size of restoration projects in the same ecosystem type between the two states to examine whether the size difference can be explained by interstate factors other than the difference in aridity. In general, arid environments may demonstrate relatively less modification and use by humans (e.g., Newbold et al. 2015), providing larger uninterrupted habitat that can be restored as compared to mesic systems.

The cost of restoration reported in our study was correlated with the size of restoration projects. Not surprisingly, projects larger in size were associated with lower per unit area cost, likely due both to reduced per unit area establishment cost (Powell et al. 2017) and to budget constraints (Cabin et al. 2010; Ager et al. 2013; Li et al. 2020). Nevertheless, only a small amount of the variation in per unit area cost was explained by the change in area size. More variation (22%) was explained by the difference in the aridity of restored ecosystems, with mesic systems associated with higher per unit area cost. This cost difference might be partially explained by the longer duration of restoration projects and the more frequent reporting of

413 construction as the most expensive restoration component in mesic systems. Restoration in
414 riparian and wetlands systems is more likely to require construction to restore hydrologic
415 functions (e.g., Cooper et al. 2017), which can increase project cost substantially. Moreover,
416 restoration projects in mesic areas, such as riparian habitat, are more likely to use strategies of
417 whole plant installation instead of seeding (Palma & Laurance 2015), which can significantly
418 increase costs in plant materials and labor. Notably, our results did not indicate a significant
419 decline in the use of passive restoration in mesic systems as compared to arid/semiarid systems
420 despite the common understanding that active restoration becomes more necessary in more
421 productive ecosystems (Dorrough et al. 2008; Rodrigues et al. 2011).

422 While the variation in the size of restoration projects and the aridity of restoration
423 systems could explain some of the differences in restoration attributes between Arizona and
424 California, other factors not identified by this study could be responsible for interstate
425 differences in other attributes. Overall, state identity explained a significant yet small amount of
426 the variation (as indicated by the small R^2 values) in the duration of post-restoration monitoring
427 and the percent time spent on passive restoration. The longer duration of post-restoration
428 monitoring in California might indicate a greater number of formal monitoring practices
429 associated with professional restoration firms or more funds available for monitoring in that
430 state. The less common use of passive restoration in California might be partially attributed to
431 higher pressure of invasive plants in that state (Stohlgren et al. 2003; van Kleunen et al. 2015),
432 which would require more active restoration of native vegetation. This speculation also was
433 backed by the significantly higher percentage of responses in California reporting weed control
434 as the most expensive component in restoration.

435 The more frequent reporting of equipment as the most expensive restoration component
436 in Arizona might suggest less availability of restoration equipment that could be shared among
437 practitioners. Also notably, while the "using native only" policy was common in both states,
438 sourcing plant materials from native nurseries was significantly more frequent in California. This
439 difference might be explained by a more developed native nursery industry in California.
440 Nurseries selling native plants are an order of magnitude more in California than in Arizona
441 (Hall et al. 2011). In addition, the existence of California Native Plant Link Exchange facilitates
442 the procurement of native plants from nurseries. These interstate differences may suggest the
443 need for restoration stakeholders in Arizona to strengthen collaboration and form entities such as
444 restoration cooperatives. These cooperatives will enable a greater sharing of resources and
445 information, and thus facilitate the development of a more robust native plant supply-demand
446 network and more convenient equipment sharing, in addition to addressing other common
447 obstacles faced by restoration stakeholders in Arizona.
448 The long-term success of an ecological restoration program requires common adoption of
449 critical practices such as the use of reference sites for evaluating restoration outcomes (White &
450 Walker 1997), the use of native plants for restoring food webs (Pocock et al. 2012), and the
451 implementation of post-restoration monitoring (Block et al. 2001; Gillilan et al. 2005; Clark et al.
452 2019). Our survey results suggested these practices were common in both states. Nevertheless, it
453 is unclear whether practitioners conducted evaluation and monitoring using metrics and
454 standards recommended by researchers (Clark et al. 2019; Ruiz-Jaen & Aide 2005). For
455 example, our survey did not specifically evaluate the quality of post-restoration monitoring. Both
456 a single site walk-through and multiple intensive inventories can be considered monitoring.
457 Other studies have suggested although practitioners generally understand the value of

458 monitoring, they are less likely to conduct intensive measure of pre-defined indicators to monitor
459 the success of restoration due to practical constraints (Hagger et al. 2017; Clark et al. 2019).
460 Given that funding usually limits the implementation of restoration monitoring
461 (Bernhardt et al. 2007; Clark et al. 2019), research may focus on approaches that can reduce the
462 financial and labor burden brought by post-restoration monitoring (Clewell & Rieger 1997) and
463 thus encourage more implementation of longer-term monitoring, especially in states like Arizona
464 that may receive less government funding for restoration. For example, the use of drones for
465 restoration monitoring is becoming an easy way to provide fast, general management outcome
466 information across large landscapes (Knoth et al. 2013). Drone imagery has shown its usefulness
467 in monitoring the outcome of the large-scale thinning of ponderosa pine forest in northern
468 Arizona (Belmonte et al. 2020).
469 Overall, our synthesis of survey responses by restoration stakeholders suggests (1)
470 although most common types of ecosystems for restoration varies between states like California
471 and Arizona with different climatic conditions, mesic systems such as riparian habitat receives
472 high priority for restoration even under arid climate. Research and implementation efforts may
473 focus on increasing the cost-effectiveness of restoration in mesic systems, where per unit area
474 cost tends to be higher and duration tends to be longer. Yet stakeholders need to be aware that
475 increase in cost-effectiveness is not always associated with more desirable outcome of a
476 restoration project (Kimball et al. 2015). (2) While enhancing biodiversity is a common
477 motivation among restoration projects, different social-political interests and ecological
478 conditions often result in diverse, interdependent restoration goals. Incorporating the holistic
479 design principle may help restoration projects meet a large number of goals that are more
480 representative of interests among diverse social groups (Naveh 2007). (3) The restoration

enterprise in Arizona may not reach the same level of development as that in California as suggested by the shorter duration of post-restoration monitoring, the less possibility of sourcing plant materials from native plant nurseries, and higher expense in equipment use. Enhanced resource and information sharing, through a cooperative and network structure, may accelerate the development of restoration enterprise in Arizona or other geopolitical regions with similar challenges in funding, infrastructure and business development.

ACKNOWLEDGMENTS

The authors thank all survey participants, Hannah Farrell, and three anonymous reviewers for their contribution to this article.

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619

TABLES

Table 1. Shared questions listed in surveys given to restoration practitioners in Arizona and California and were analyzed in this study. Each question corresponds to the variable acquired from this question, the type of this variable, and the transformation (if any) applied to the variable, all of which were listed in adjacent columns.

Survey Question	**Variable acquired**	**Type of variable**	**Transformation**
1a. What is your organization affiliation (check all that apply)? □Agency □University □NGO □Private business (e.g. rancher, consultant) □Other_____	Organization	Categorical	None
1b. What is your role or position in the organization (check all that apply)? □Land manager □Rancher/Farmer □Academic researcher □Business owner □Restoration practitioner □Science advisor □Land owner □Cooperative Extension □Management advisor (e.g. PCA) □Other_____	Occupation	Categorical	None
2. In what state and county do you conduct the majority of your work?	State	Categorical	None
3. What system do you work in the most? □Grassland/rangeland □Streams/rivers □Riparian	Ecosystem for restoration	Categorical	None

□Desert □Urban/right of way □Montane meadow □Wetland □Forest □Cropland □Other_____			
4. For the system you work in the most, what is the typical size of a restoration project? _____acres	Size of restoration	Continuous numeric	$\log_{10}$ after converting to hectares
5. For the system you work in the most, how much (per acre) does a typical restoration project cost (from design to implementation, excluding monitoring)? $_____/acre	Per unit area cost of restoration	Continuous numeric	$\log_{10}$† after converting to US dollars per hectare
6. For the system you work in the most, what is the most expensive component of a typical restoration project? ☐ Labor ☐ Plant materials ☐ Weed control ☐ Equipment ☐ Design ☐ Monitoring ☐ Other_____	Most expensive component of restoration	Categorical	None
7. For the system you work in the most, how long does a typical restoration project take to complete (from design to implementation, excluding monitoring)? _____	Duration of restoration	Continuous numeric	$\log_{10}$ after converting to years
8. For the system you work in the most, how often do you monitor a restoration project after it is completed? (circle one) Never Rarely Sometimes Often Always	Frequency of post-restoration monitoring	Likert-scale	Discrete integers: -2 (never) – 0 (sometimes) – 2 (always)
9. For the system you work in the most, how many years after deploying a restoration project do you typically monitor a site? _____	Duration of post-restoration monitoring	Continuous numeric	$\log_{10}$††

10. For the system you work in the most, how often do you use a reference site? (circle one) Never Rarely Sometimes Often Always	Frequency of using a reference site	Likert-scale	Discrete integers: -2 (never) – 0 (sometimes) – 2 (always)
11. For the system you work in the most, from where do you get your plant materials for restoration projects? ☐ Field collected ☐ Native nurseries ☐ Conventional nurseries ☐ Your own greenhouse ☐ Other_____	Source of plant materials	Categorical	None
12. For the system you work in the most, what percentage of the time do you employ passive restoration only (the cessation of some damaging activity such as mining or grazing)? _____	Percent time passive restoration was employed	Continuous numeric	None
13. Does your organization have a formal policy about using only natives for restoration? No Yes	Having a formal policy of using only native plants	Categorical /Binary	0 (No), 1 (Yes)
14. For the system you work in the most, what is your typical top restoration goal? ☐ Enhance biodiversity ☐ Erosion control ☐ Plant cover ☐ Weed control ☐ Water filtration ☐ Wildlife habitat ☐ Other_____	Restoration goal	Categorical	None

† Log transformation was performed after adding $1 to all data points.

†† Log transformation was performed after adding 0.2 year to data points of 0s, and converting answers of infinite monitoring to 30 years of post-restoration monitoring.

628

629 **Table 2.** Results of statistical inferences of numeric and Likert-scale response variables as a
630 function of either state or size of restoration, or both. Some of the response variables were
631 transformed (see Table 1) and the results were reported in the form of transformed variables.
632 Presented were only coefficients for explanatory variables deemed significant by each test and
633 the associated stepwise regression (if any). R^2 of linear models are for those selected as the best
634 models by AIC-based stepwise regression when both state and size of restoration were evaluated.

Response variable	Intercept	Effect size of "state" (Arizona as the baseline)	Effect size of "size of restoration" {$\log_{10}$ (hectares)}	Test statistics of the selected model	*p* value of the selected model	R^2 of the selected model
Size of restoration {$\log_{10}$ (hectares)}	1.687	-0.833	N/A	$F_{1,188} = 15.75$	0.0001	0.077
Cost of restoration {$\log_{10}$ (US dollars per hectare)}	1.895	NS	-0.250	$F_{1,99} = 5.094$	0.026	0.049
Duration of a restoration project {$\log_{10}$(years)}	0.089	0.300	0.066	$F_{2,161} = 9.041$	0.0002	0.101
Duration of post-restoration monitoring {$\log_{10}$(years)}	0.563	0.160	NS	$F_{1,151} = 4.355$	0.039	0.028
Percent time in which passive restoration was employed (% of time)	38.951	-17.336	NS	$F_{1,140} = 8.256$	0.005	0.056

The frequency of using a reference site (Likert-scale -2 – +2)	0.628	NS	NS	$t_{178} = 7.562$	$<10^{-12}$	N/A
The frequency of post-restoration monitoring (Likert-scale -2 – +2)	0.8242	NS	NS	$t_{180} = 12.45$	$< 10^{-16}$	N/A

635

636

637 **Table 3.** Results of statistical inferences of numeric and Likert-scale response variables as a
638 function of ecosystem type (mesic vs. arid/semiarid). Some of the response variables were
639 transformed (see Table 1) and the results were reported in the form of transformed variables.
640 Significant or marginal significant differences between the two ecosystem types were shown in
641 bold.

Response variable	Mean of arid/semiarid ecosystem	Mean of mesic ecosystem	Difference in mean between mesic and arid/semiarid system	*F* statistic	*p* value	R^2
Size of restoration {$\log_{10}$ (hectares)}	1.835	1.240	**-0.595**	$F_{1,110} = 5.381$	0.022	0.047
Cost of restoration {$\log_{10}$ (US dollars per hectare)}	0.870	2.319	**1.449**	$F_{1,64} = 18.01$	0.00007	0.220
Duration of a restoration project {$\log_{10}$(years)}	0.138	0.407	**0.269**	$F_{1,101} = 10.06$	0.002	0.091
Duration of post-restoration monitoring {$\log_{10}$(years)}	0.561	0.654	0.093	$F_{1,93} = 0.852$	0.358	0.010
Percent time in which passive restoration was employed (% of time)	37.63	33.07	-4.56	$F_{1,89} = 0.35$	0.556	0.004

The frequency of using a reference site (Likert-scale -2 – +2)	0.687	0.755	0.058	$F_{1,112} = 0.081$	0.777	0.001
The frequency of post-restoration monitoring (Likert-scale -2 – +2)	0.781	0.777	-0.004	$F_{1,112} = 0.0004$	0.983	0.000

642

FIGURE CAPTIONS

Fig 1. Numbers and percentage of responses indicating (a) the types of organization by which the survey participants were employed, (b) the occupation of the participants, and (c) the type of ecosystem, in which the participants worked most. The number of responses in each category is shown in parentheses following the bar indicating the percentage. Stars (*) in panel C indicate comparisons that were significantly different according to proportional (Chi-squared) tests.

Fig 2. The number (in parentheses) and percentage (bar) of responses reporting (a) the top restoration goals, (b) the most expensive component of a typical restoration project, and (c) the source of plant materials for restoration. Left panels show the difference between Arizona (black) and California (grey). Right panels show the difference between arid/semiarid (magenta) and mesic (blue) ecosystems. Stars (*) indicate comparisons that were significantly different according to proportional (Chi-squared) tests.

Fig 3. Numeric response variables (a) per hectare cost of restoration, (b) duration of restoration projects, (c) duration of post-restoration monitoring, and (d) percent time in which restoration was employed as a function of size of a restoration project (hectares on a logarithmic scale), state, and the ecosystem types. Responses in arid/semiarid ecosystems (magenta points) included those reported “grassland/rangeland”, “desert”, or the combination of the two as the only ecosystem(s) of restoration. Responses in mesic ecosystems (blue points) included those reported “streams/rivers”, “riparian”, “wetland”, “montane meadows”, “forest”, or any combination of them as the only restoration system(s). Responses that reported other restoration ecosystems were classified as uncertain (grey points) even if they also reported any of the aforementioned systems. The shortest non-zero durations of post-restoration monitoring shown in the figure (c)

were indeed zeros. A value of 0.2 was added to these zeroes to enable log transformation while preventing the creation of outliers.

FIGURES

Fig 1.

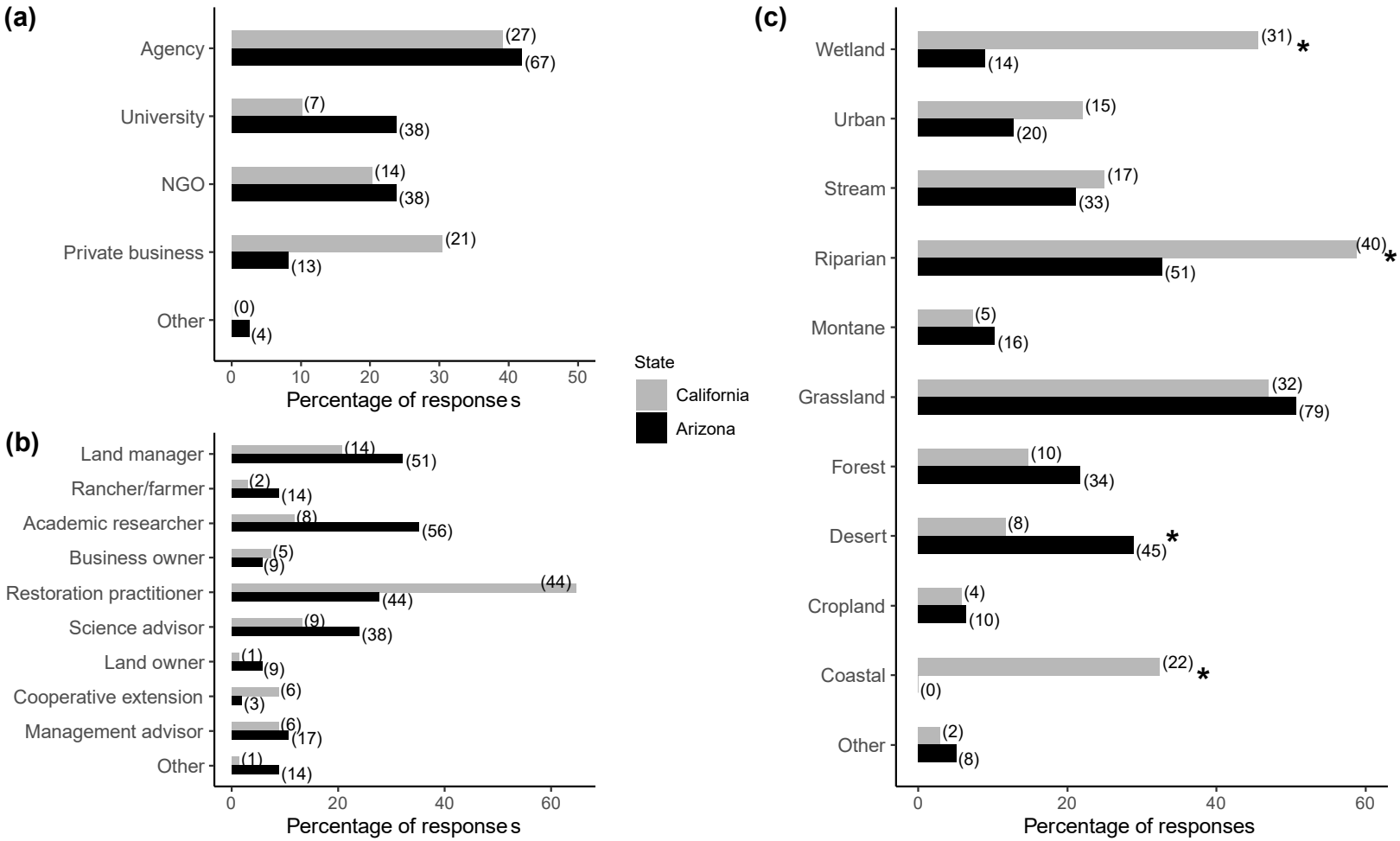


Fig 2.

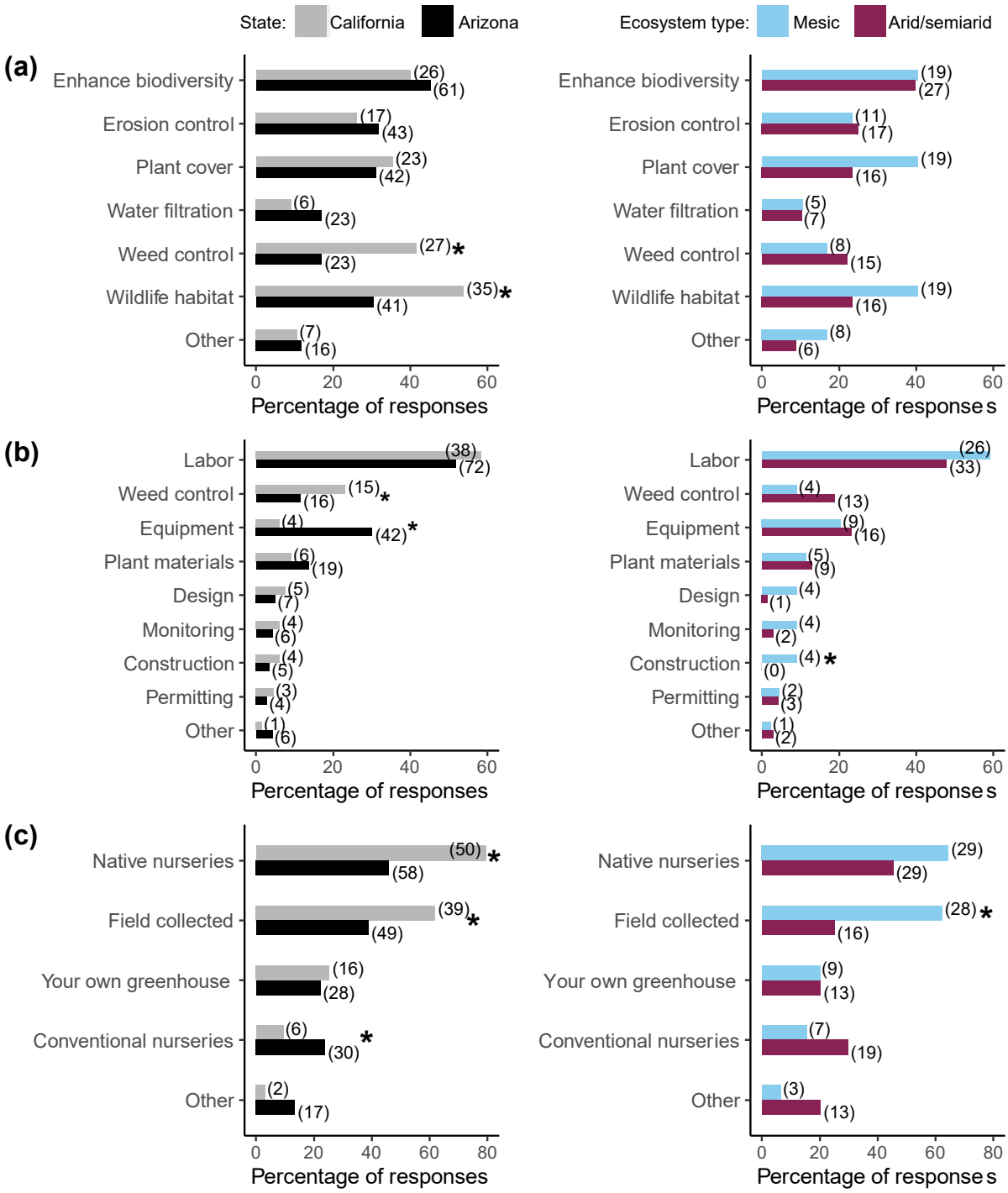
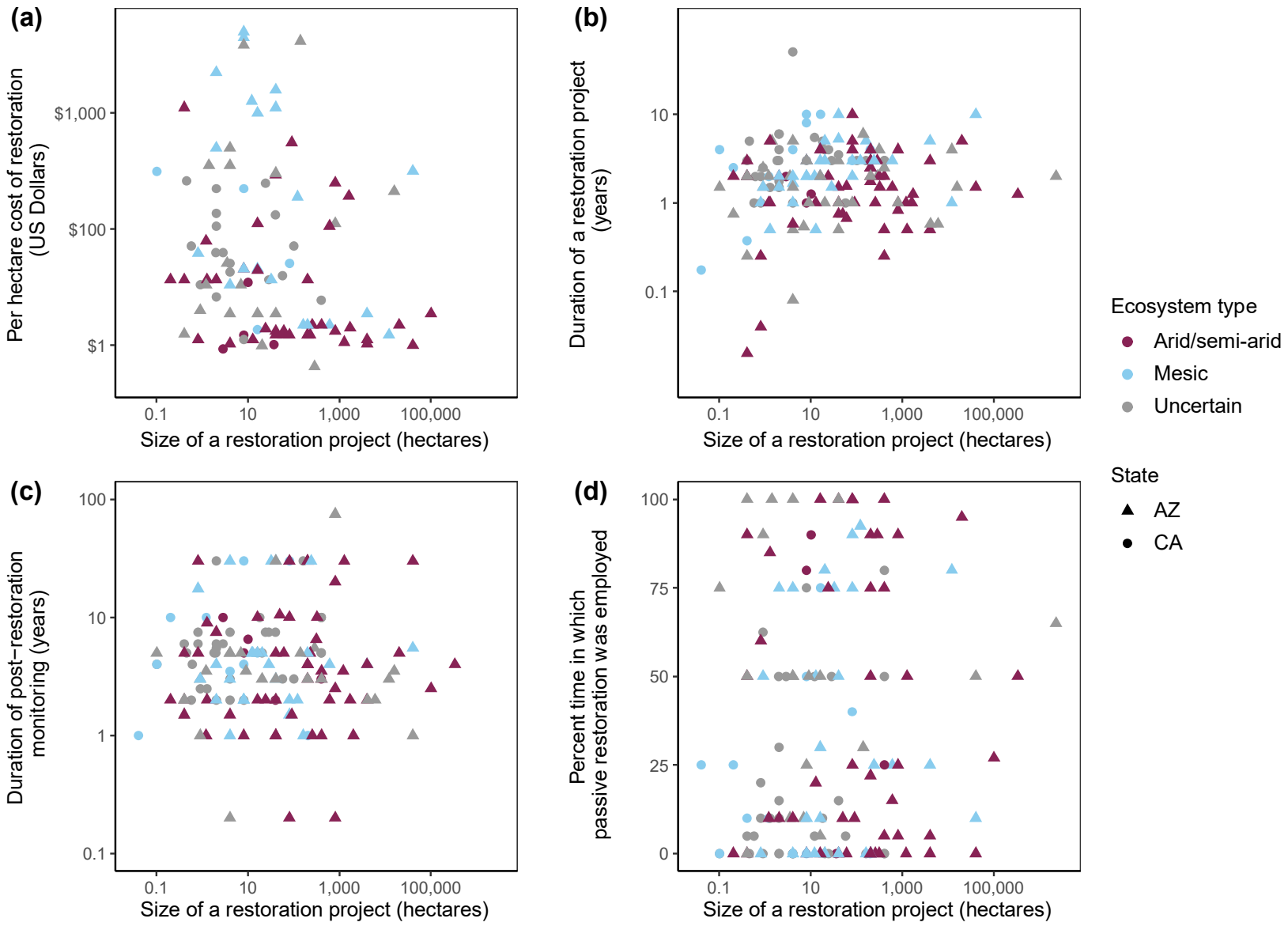

State: California Arizona
Ecosystem type: Mesic Arid/semiarid
(a)
Enhance biodiversity
Erosion control
Plant cover
Water filtration
Weed control
Wildlife habitat
Other
(26) (61)
(17) (43)
(23) (42)
(6) (23)
(27)* (23)
(35)* (41)
(7) (16)
(19) (27)
(11) (17)
(19) (16)
(5) (7)
(8) (15)
(19) (16)
(8) (6)
0 20 40 60
Percentage of responses
(b)
Labor
Weed control
Equipment
Plant materials
Design
Monitoring
Construction
Permitting
Other
(38) (72)
(15)* (16)
(4) (42)*
(6) (19)
(5) (7)
(4) (6)
(4) (5)
(3) (4)
(1) (6)
(26) (33)
(4) (13)
(9) (16)
(5) (9)
(4) (1)
(4) (2)
(4)* (0)
(2) (3)
(1) (2)
0 20 40 60
Percentage of responses
(c)
Native nurseries
Field collected
Your own greenhouse
Conventional nurseries
Other
(50)* (58)
(39)* (49)
(16) (28)
(6) (30)*
(2) (17)
(29) (29)
(28)* (16)
(9) (13)
(7) (19)
(3) (13)
0 20 40 60 80
Percentage of responses

Fig 3.


(a)
Per hectare cost of restoration (US Dollars)
$1,000
$100
$1
0.1
10
1,000
100,000
Size of a restoration project (hectares)
(b)
Duration of a restoration project (years)
10
1
0.1
0.1
10
1,000
100,000
Size of a restoration project (hectares)
Ecosystem type
Arid/semi-arid
Mesic
Uncertain
State
AZ
CA
(c)
Duration of post−restoration monitoring (years)
100
10
1
0.1
0.1
10
1,000
100,000
Size of a restoration project (hectares)
(d)
Percent time in which passive restoration was employed
100
75
50
25
0
0.1
10
1,000
100,000
Size of a restoration project (hectares)