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Evaluating the impact of ecosystem service assessments on decision-makers

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ABSTRACT

Ecosystem services support human livelihoods and economies but are declining in many places. Ecosystem service assessments estimate the benefits that nature provides to people and can be used to evaluate trade-offs in impacts and changes resulting from land use decisions. Such assessments can affect the capacity of decision-makers to make sustainable land use decisions, but the actual impact of such projects on decision-maker attitudes is almost entirely unstudied. We addressed this knowledge gap by evaluating the impact of an ecosystem service assessment on decision-makers in California. We asked how decision-makers' understanding of and attitudes about ecosystem services changed "pre-" and "post-" assessments and between treatment groups where ecosystem services were assessed and a comparison group where ecosystem services were not assessed. Mixed methods included regression models to estimate the treatment effect of the assessment (using a difference-in-differences approach), as well as interviews and direct observations to further understand how decision-makers responded to the assessment. Regression results showed small increases relative to the comparison group in decision-maker understanding of ecosystem services and perceived relevance of ecosystem services to their work. Interviews confirmed that decision-makers learned specific ways that they could use ecosystem services in conservation and development decisions and believed that doing so would improve outcomes. These results demonstrate how ecosystem services assessments can facilitate a conceptual shift in the minds of decision-makers, which is a necessary ingredient for subsequent policy impact. Impact evaluation studies of this type – that estimate a counterfactual and explore rival explanations for observed outcomes – are needed to truly understand whether ecosystem service projects impact decision-makers and, ultimately, produce outcomes for environmental and human well-being.

1. Introduction

Land use and land management decisions have significant impacts on ecosystems and ecosystem services (ES), the valuable goods and services that ecosystems provide to people (Daily, 1997; Polasky et al., 2011). Increasingly, efforts to conserve, protect, or restore ES aim to influence land use decisions so that they incorporate information about the values of ES (Chan et al., 2006; Daily et al., 2011; Goldman and Tallis, 2009). Efforts to incorporate ES knowledge into policy rest on basic assumptions that this knowledge will improve decisions and result in improved environmental and human well-being outcomes.

But there is a lack of sound evidence about the impact ES knowledge has on the people who make land use and land management decisions, or how decision-makers use ES knowledge (Laurans et al., 2013; Mermet et al., 2014). Many valuation studies mention prospective or intended roles for ES knowledge in terms of informative, technical, or decisive uses, but rarely do these studies describe actual use (Laurans et al., 2013). In a survey of researchers, Fisher et al. (2008) found that ES research was used to inform policy agents, support policy initiatives, and directly influence government policy and investment. A recent review of three international case studies describes similar ways ES knowledge is used: *conceptually* to raise awareness and reframe dialogues, *strategically* to build support for plans or policies, and *instrumentally* to make specific decisions (McKenzie et al., 2014). If conservation science is to inform improved land use decisions, it is

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critical to better understand what difference ES knowledge makes in the minds of land use decision-makers (McKenzie et al., 2011).

According to theories of the science-policy interface, knowledge has an important role in shaping decisions. Theory suggests that decision-makers are more likely to trust and use knowledge that they perceive as salient (i.e., relevant to the needs of decision-makers), credible (i.e., based on expert, reliable science), and legitimate (i.e., unbiased and inclusive of diverse perspectives) (Cash et al., 2003; Cook et al., 2013; Keller, 2010). A simple, linear model of policymaking described by Meier (1991) includes a role for knowledge early in the policy process, when it can affect the understanding and attitudes of policymakers. The more complex stages model (Grindle and Thomas, 1991), the policy streams model (Kingdon, 2011), and the advocacy coalition model of policy processes (Sabatier and Weible, 2014) all portray a similar key role for knowledge. These models share several general components: decision-makers and other stakeholders perceive a problem, gather and evaluate knowledge about the problem and proposed solutions, and acknowledge the need to act on policy options.

Knowledge about the value of ES could thus be valuable as an early lens for shaping how decision-makers identify and understand problems, as well as a tool for evaluating proposed policy options. For ecosystem services specifically, a conceptual framework first presented by Ruckelshaus et al. (2015) and built upon by Posner et al. (2016) describes several pathways through which knowledge impacts policy decisions (Fig. 1). Here we focus mainly on pathway 2, when ES knowledge helps shape the minds of decision makers by raising awareness and providing an ES focus for stakeholders. We also describe the emergence of pathway 3, through which decision makers and stakeholders build support for particular policy options and use language related to ES as a frame within policy dialogues. Lastly, we investigate the potential for pathway 4 and assess how decision makers envision using ES knowledge to evaluate projects, compare options, and design new policies and plans.

The health, policy, and international development fields have long included systematic impact evaluation research, and researchers and practitioners in conservation increasingly recognize the need for improved evidence of impact (Ferraro and Pattanayak, 2006; Fisher et al., 2013). The complexity and scale of real world social-environmental interactions has made rigorous and quantitative evaluation of impact in conservation difficult, but recent research is moving beyond anecdotal evidence and testing specific causal mechanisms through which impact may occur (Andam et al., 2010; Arriagada et al., 2012; Ferraro and Hanauer, 2014b; Miteva et al., 2012; Naidoo and Johnson, 2013; Pfaff et al., 2008). In order to understand how conservation programs and projects lead to improved outcomes for biodiversity and well-being, these studies use control groups and statistical matching to estimate impact (Ferraro, 2009; Margoluis et al., 2009).

Our study complements this growing body of work, which tends to focus on the impact of conservation policy on environmental outcomes (pathway 5 in Fig. 1). Instead, we focus on impact at an earlier stage of the policymaking process – when ES knowledge has an impact on the minds of those proposing and making policy decisions (pathway 2 in Fig. 1). We aim to detect whether knowledge about the value of ES changes the capacity of natural resource managers and conservation decision-makers to make conservation-oriented decisions. In the process, we evaluate the importance and impact of ES knowledge as a resource for decision-makers.

Specifically, we ask: do ES valuation projects impact local decision-makers' 1) understanding of ES and natural capital concepts, and 2) attitudes about conservation and planning approaches based on these concepts? We follow ES assessments in two counties in California, employing quantitative methods to compare changes in decision-maker understanding and attitudes with those in neighboring counties without assessments. We also use qualitative methods to explore why understanding and attitudes did or did not change. Tracking change in decision-makers and their capacity to consider ES is vital in order to link scientific knowledge with action and to understand the difference that ES knowledge may make.

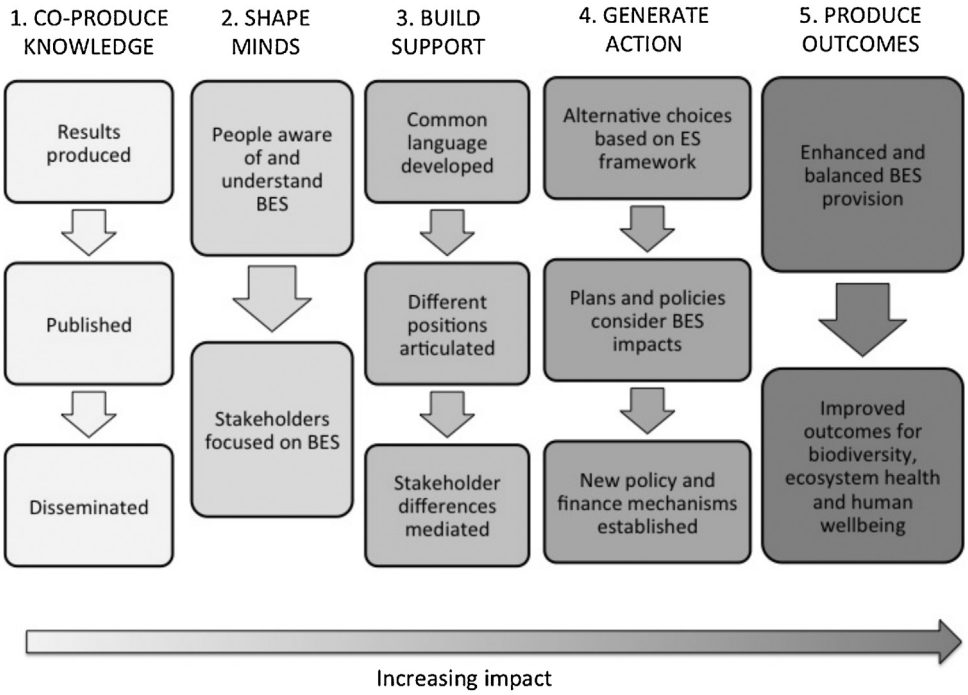

Fig. 1. Framework for how ecosystem services knowledge leads to impact. Five different pathways to impact are represented as columns with increasing impact the further one moves to the right. Our study focuses mainly on pathways 2 and 3. Based on Ruckelshaus et al. (2015) and modified by Posner et al. (2016).

Table 1
Outcome variables and associated survey questions. Survey respondents were asked to tell us how much they agree with the following statements. (1–don't know; 2–strongly disagree; 3–disagree; 4–neutral; 5–agree; 6–strongly agree). The third column indicates the panel in Fig. 2 associated with each question.

Outcome	Survey question	Fig. 2 panel
ES relevant to organization	An ecosystem services approach is relevant to my company's/organization's work.	A
ES relevant to work	The economic value of ecosystem services is relevant to my own work.	B
ES is credible	The economic value of ecosystem services can be quantified in scientifically credible ways.	C
ES is legitimate	Ecosystem service knowledge is legitimate – gathered in a way that is complete, correct, and unbiased.	D
Capacity to monitor impacts to ES	Capacity to monitor impacts to ecosystem services exists in my county/region.	E
Capacity to implement ES policies	Capacity to implement policies or plans about ecosystem services exists in my county/region.	F
Understanding of ES	I have a solid understanding of what the term *ecosystem services* means.	G

2. Methods

"Healthy Lands, Healthy Economies" was a regional initiative designed to demonstrate the economic value of conservation in Sonoma, Santa Clara, and Santa Cruz Counties in California (herein referred to as "the initiative"). One of the goals of the initiative was to measure the tangible effect that protecting natural areas had on local and regional economies. The multi-year project resulted in ES valuation reports for Santa Clara County (Batker et al., 2014), Santa Cruz County (Schmidt et al., 2014), and Sonoma County (forthcoming) that framed the natural resources of each county as capital assets requiring investment in order to maintain a flow of economic benefits. The assessment team consisted of economists, ecologists, and conservation planners who worked together to identify and quantify the economic and community benefits achieved by investing in working lands, natural areas, and water resources in the greater San Francisco Bay Area.

We used a mixed methods approach to evaluate the impact of the initiative and the subsequent ES valuation reports on decision-makers in Santa Cruz and Santa Clara Counties (Bamberger, 2012; Creswell, 2009; Wholey et al., 2010). This approach allowed us to consider multiple sources of quantitative and qualitative evidence in our analysis and construct a more complete description of impact. We evaluated the initiative, which was conducted in a similar way in both counties, and compared the impacts of the ES assessment between Santa Clara, Santa Cruz, and a comparison group. Counties throughout California have different demographics and cultures (i.e. Santa Clara is a technology business hub while neighboring Santa Cruz is a coastal recreation destination) and different natural resource issues and management approaches (i.e. Santa Clara County has one large consolidated water district, while Santa Cruz County has many small individual water districts) that could affect the dissemination and potential use of ES knowledge. We focused on the impact of the initiative on the same kinds of decision-makers between groups, but we did not have enough nor appropriate data on covariates to create comparable matched units. Matching is most effective with larger samples and more data on observed covariates.

2.1. Quantitative methods

We surveyed individuals in two treatment groups (Santa Clara and Santa Cruz counties, where ES valuation studies were conducted and reported) and a comparison group (8 neighboring counties, where no county-wide ES valuation studies were occurring). We administered the survey electronically using Survey Monkey before the initiative was launched in Winter 2013 and after release of the final county-level ES valuation reports in Winter 2015. Survey respondents were land use and conservation decision-makers identified by the assessment team as the intended audience for the initiative (for example, general managers of water districts, county planners, and executive directors of conservation NGOs).

In the comparison group of 63 individuals, we received 10 responses to both the pre- and post- survey (16% response rate). These 10 individuals were from Alameda, Contra Costa, Marin, Monterey, Napa, San Mateo, San Luis Obispo, and Solano Counties. In each of the Santa Cruz and Santa Clara groups, we received 9 responses to the pre- and post- surveys (18% response rate). Response rates were higher for the pre- survey, but fewer of these individuals responded to the post- survey and some initial respondents moved jobs or locations during the initiative. We used the panel data of individuals who responded to both the pre- and post- survey. Our analyses were therefore based on a database of 28 pre- and 28 post- survey responses: a total of 20 in the comparison group, 18 in Santa Cruz, and 18 in Santa Clara. The first round of surveys informed the design of interview questions used in the qualitative analysis.

The survey consisted of open-response and 5-point Likert-scale questions; we used the latter in our quantitative analysis (SI 1). For outcome variables, we used mean responses with standard errors for each of the two groups (i.e., treatment and comparison) for each of the seven survey questions (Table 1).

We used a difference-in-differences approach to estimate the effect of the initiative on decision-makers (Gertler et al., 2010; Khandker et al., 2010). We calculated the before-after differences for outcome variables in the treatment groups; calculated the before-after differences for the same variables in the comparison group; and estimated the average treatment effect as the difference in the differences between each treatment group and the comparison group (Table 2).

We then specified time-series linear regression models:

$$Y_{it} = \beta_0 + \beta_1 P_{it} + \beta_2 G_{it} + \beta_3 (P_{it} \times G_{it}) + \varepsilon_{it}$$

where Y_{it} is a decision-maker outcome of interest, P_{it} is a dummy variable for time period where pre-initiative periods are 0 and post-initiative are 1, and G_{it} is a dummy variable for group where comparison group is 0 and the treatment county is 1 (Branas et al.,

Table 2
The difference-in-differences method. The two treatment groups of Santa Clara and Santa Cruz Counties had the ecosystem services initiative, whereas the comparison group composed of individuals from nearby counties did not have a county-wide ecosystem services assessment. $Y_{C,pre}$ refers to an outcome variable for the comparison group before the initiative.

	Comparison	Santa Clara or Santa Cruz	
Pre	$Y_{C,pre}$	$Y_{SC,pre}$	
Post	$Y_{C,pre}$	$Y_{SC,post}$	
Difference	$Y_{C,post} - Y_{C,pre}$	$Y_{SC,post} - Y_{SC,pre}$	$(Y_{C,post} - Y_{C,pre}) - (Y_{SC,post} - Y_{SC,pre})$ = estimate of treatment effect

2011), and P_{it} x G_{it} is the interaction between time period and group. The coefficient for this interaction term, β_3, is identical to the difference-in-differences term calculated above, and estimates the average effect of the initiative on the outcome (Meyer, 1995). We used the regression framework in order to obtain standard errors for the treatment effect and test if it was statistically significant. All data analysis was performed in R (R, 2011).

There are a variety of ways to do impact evaluation. Counterfactual thinking considers the hypothetical situation in which the treatment is absent, and it is an important part of considering rival explanations for observed outcomes (Ferraro and Hanauer, 2014a). Difference-in-differences is valuable in that it allows quantitative comparison between a treatment group and an estimate of the counterfactual. It does, however, rest on the assumption of equal trends in outcomes among all counties in the absence of the initiative, an assumption that could be tested with surveys at multiple pre-initiative time periods. There are stronger evaluation designs than difference-in-differences (e.g. experimental design, or statistically matched controls), but we were limited by poor data on observable outcomes and unobservable sources of bias, which is often the case in environmental evaluation (Ferraro and Miranda, 2014). The limited data available means that our findings are best interpreted as suggestive and useful for guiding future studies.

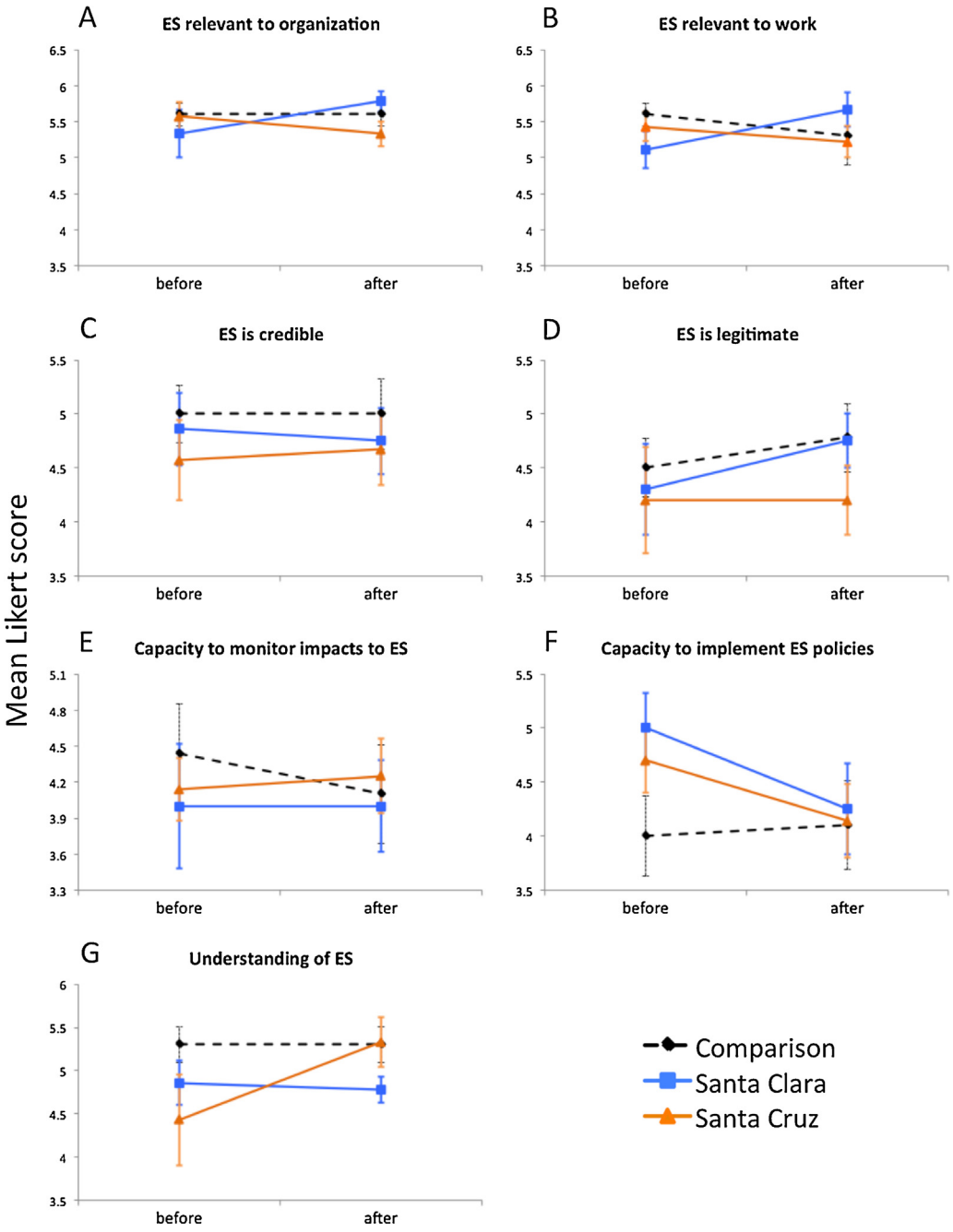

Fig. 2. Differences in outcomes between the comparison group and the two treatment groups of Santa Clara and Santa Cruz Counties. Data points represent mean outcomes with standard errors before and after the initiative for the three groups. Each panel corresponds to a survey question asked before and after ES assessments were conducted (Table 1).

Table 3
Difference-in-differences estimates of the impact of the initiative on decision-maker outcomes. β_3 is also the coefficient of the interaction term from our regression models, comparing each treatment county to the comparison group.

Outcome	Estimate (β_3)	SE	p-value
Santa Clara			
ES relevant to organization	0.44	0.42	0.30
ES relevant to work*	**0.86**	**0.57**	**0.14**
ES is credible	−0.11	0.63	0.87
ES is legitimate	0.19	0.64	0.77
Capacity to monitor impacts to ES	0.34	0.87	0.70
Capacity to implement ES policies	−0.85	0.77	0.28
Understanding of ES	−0.08	0.42	0.85
Santa Cruz			
ES relevant to organization	−0.24	0.35	0.50
ES relevant to work	0.09	0.56	0.87
ES is credible	0.10	0.66	0.89
ES is legitimate	−0.26	0.70	0.72
Capacity to monitor impacts to ES	0.45	0.75	0.55
Capacity to implement ES policies	−0.53	0.76	0.49
Understanding of ES*	**0.90**	**0.61**	**0.15**

Abbreviation: SE, standard error.
* $p \leq 0.15$.

2.2. Qualitative methods

We used a case study approach to gather, organize, and analyze data for qualitative analyses in the Santa Cruz and Santa Clara groups (Yin, 2009). We conducted direct observations of 5 workshops and meetings with stakeholders in Santa Cruz County and 5 in Santa Clara County from Fall 2012 through Winter 2013. This data collection technique allowed us to systematically observe decision processes and early dialogue using a structured, pre-designed observation record form (SI 2) (Taylor-Powell and Steele, 1996). We observed decision-makers and scientists in their natural settings as they engaged with ES and natural capital concepts during the process of the ES valuation study.

We also conducted 11 semi-structured interviews with stakeholders before the initiative was launched and 12 interviews after the county reports were published (23 total interviews in Santa Cruz and Santa Clara Counties). Interviewees were similar land use and conservation decision-makers identified by the assessment team for the survey. Interview questions built upon the results of the pre-initiative survey. The questions explored how individuals reported understanding and perceiving ecosystem services concepts, their attitudes about ecosystem services as a conservation approach, and whether they believed that ecosystem services would be useful and relevant to their land use and natural resource management decisions (SI 3). We also asked interviewees to comment on what they thought would occur if there was no ES valuation study in their county in order to qualitatively explore the counterfactual. We used content analysis on the interviews and direct observation records to understand the impact of the initiative.

3. Results

3.1. Quantitative results

Difference-in-differences estimates on the outcome variables showed mixed results (Fig. 2). From our regression analyses, no interaction terms were significant at the 0.05 level (Table 3). These are results for differences in pre/post outcomes between each of the two treatment counties and the comparison group. Here we present the results of our analysis. In the discussion section that follows, we interpret these findings and summarize what they mean for the overall impact of the initiative.

We emphasize two difference in differences results with a *p*-value ≤ 0.15 (because our small sample sizes make it difficult to detect differences). In Santa Clara County, we found an increase in the perceived relevance of ES to one's work (Fig. 2B). In Santa Cruz, our results show an increase in self-reported understanding of ES (Fig. 2G). Other relationships were non-significant, including positive estimates of impact in Santa Clara for the perceived relevance and legitimacy of ES and the capacity to monitor ES; and in Santa Cruz for perceived credibility of ES and relevance of ES to a person's work, understanding of ES, and capacity to monitor ES. In both counties, non-significant negative impacts were found for the capacity to implement policies or plans about ES.

For those outcome variables with marginally significant differences in difference ($p \leq 0.15$), we examined our original survey responses more closely. We found changes between the pre and post periods in the percentage of respondents who agreed or strongly agreed to the questions we used to measure outcomes (Table 4). For example, "understanding of ES" showed the largest increase of all outcomes in both counties relative to comparison group: in Santa Clara, from 56% pre-initiative to 78% post-initiative; in Santa Cruz, from 33% to 78%; and in the comparison group, no increase from 90%. Also, "relevant to their work" increased from 78% to 89% in both Santa Clara and Santa Cruz, but went down from 100% to 90% in the comparison group. The decrease in perceived capacity to implement policies or plans about ES is also evident in the original survey results. In Santa Clara, the percentage of respondents who agreed or strongly agreed declined from 78% pre-initiative to 56% post-initiative; in Santa Cruz, from 56% to 33%; in the comparison group, from 50% to 40%.

3.2. Qualitative results

The results of our qualitative analysis provide additional insight into the impact of the initiative. Again, there were mixed responses among decision-makers, but the interviews uncovered stronger evidence of impact. Here we highlight 4 main themes from our analysis of qualitative interview and direct observation data. In the final discussion section, we synthesize and interpret the quantitative and qualitative results.

Table 4
Percentages of respondents who agreed or strongly agreed with statements about ecosystem services in our survey questions.

	Santa Clara pre	Santa Clara post	Santa Cruz pre	Santa Cruz post	Comparison pre	Comparison post
Relevance to org	89%	100%	78%	100%	100%	100%
Relevance to work[a]	**78%**	**89%**	**78%**	**89%**	**100%**	**90%**
Credibility of ES	67%	67%	44%	56%	60%	70%
Legitimacy of ES	33%	56%	33%	33%	30%	60%
Understanding ES[a]	**56%**	**78%**	**33%**	**78%**	**90%**	**90%**
Capacity to monitor impacts to ES	33%	33%	22%	44%	60%	60%
Capacity to implement policies[b]	**78%**	**56%**	**56%**	**33%**	**50%**	**40%**

[a] Note increase in treatment counties vs. comparison.
[b] Note larger decrease in treatment counties vs. comparison.

1) Decision-makers understood ES better, but found it a new concept for themselves and the public

The interviewees used more technical language about ES and demonstrated increased understanding of ES topics post-initiative. Interviewees reported being more comfortable discussing ES concepts. Over half of the interviewees described ES as "a new way of thinking" and "a new concept for people," even "a new paradigm." In pre-initiative interviews, they expected the initiative to "bring added information" to land use decisions. Post-initiative, more interviewees confirmed that this was occurring. Decision-makers felt that the new information provided in the initiative could inspire a different way of doing conservation with better environmental and long-term economic outcomes.

2) Decision-makers were initially skeptical of ES, but acquired ways to deal with their uncertainties

In 3 of the 12 follow up interviews, decision-makers reported initial skepticism about ES, but over the course of the initiative came to perceive ES as valuable for informing decisions. Also, 4 interviewees pre-initiative described the potential for information about ES to be either good or bad, depending on how the information would be used. Post-initiative, there was less concern about the potential misuse of ES information, for example, to inflate property values prior to open space acquisition.

Decision-makers had questions about the often-wide ranges of ES value estimates. For example: "to what extent can the ES valuation numbers be accepted as empirical and exact figures, versus just starting points for needed conversations?" Half of the interviewees post-initiative reported not having any problem with the value ranges. Others still felt the ranges could hurt the credibility of the ES value estimates, but most accepted the value ranges as useful for long-range regional-scale planning.

Decision-makers mentioned that their organizations were considering ways to internally evaluate the ES value estimates (for example, by having staff ecologists review how the ES valuation reports determined which ES were provided by different land use types). This indicated engagement with the reports. Vetting of the ES assessments, either internally within an organization or publicly, could lead to more co-production of useful ES knowledge (Cutts et al., 2011; Roux et al., 2006).

3) Decision-makers used or intended to use the ES knowledge conceptually, strategically, and instrumentally

Of all the interviewees, only 3 of the total 23 were skeptical about ES and the usefulness of ES knowledge in land use decisions. There was widespread agreement about the value of ES knowledge for framing conversations about nature and highlighting trends in environmental quality. One interviewee described how the initiative "painted a picture to demonstrate how the value of each [ES] affects people in real ways." A representative from a funding organization described how the initiative was helping ES become a regular part of their "lexicon." These results indicate conceptual use of the ES knowledge.

There was also clear evidence of strategic knowledge use. Decision-makers felt that the ES knowledge provided by the initiative would be used: to inform conversations about the potential formation of a new open space district; to build public support for conservation funding measures; and to "change legislators' thinking about the value of state parks or open space." There was also mention of building support within the business community because of how nature "provides nice views and recreation, attracting and retaining a qualified workforce."

Pre-initiative interviews found that people held a range of ideas for instrumental use of ES knowledge, but described potential use of ES knowledge with general language (for example, "it would be helpful to communicate the value of parks" or "we could build the case for the economic value of land"). Post-initiative interviews found these ideas were more focused and specific. Decision-makers described more specific intended uses: to inform coastal management and identify vulnerable areas for planned retreat vs. other actions; to "evaluate priorities and options for watershed stewardship projects (such as habitat improvement, invasive species removal, fish barrier removal, etc.)"; and to help decide whether to build desalinization plants to maintain water supply. In particular, people felt the dollar value estimates from the initiative would improve cost/benefit analysis, and inform a more balanced investment between "green" and "grey" infrastructure.

4) Decision-makers believed the initiative would help shift patterns in land use and development

An important component of our evaluation study was to ask decision-makers to consider what would occur in the absence of any ES value assessment in their counties. Interviewees all generally agreed that without the initiative, things would continue in a "business as usual" way, and "there would be a continued undervaluing of green infrastructure and an overemphasis on grey, built infrastructure." In pondering this hypothetical question, all interviewees felt that without the initiative, there would be ongoing loss of nature in the region.

4. Discussion and conclusion

We conducted one of the first formal evaluations of the impact of ES assessments on decision-makers' attitudes about, and understanding of, ES knowledge. We found evidence of the initiative's impact with our qualitative interviews, but weaker evidence of impact with our quantitative difference-in-differences analysis. Overall, the strongest impacts post-initiative were in how decision-makers felt they better understood ES (i.e. see difference in difference estimates in Fig. 2G for Santa Cruz) and envisioned more specific ways in which they could use ES knowledge in their work (which emerged from comparing interviews before and after the initiative).

Our results suggest barriers to how ES assessments impact decision-makers. In the interviews, decision-makers described a need to vet and refine the methods underpinning ES valuation before they could use the results to enact new policies. A significant challenge lies in how to effectively integrate "new" ways of valuing land into existing decision processes and tools such as cost-benefit analysis. Another challenge in impacting decisions lies in the potential mismatch between the scale of county-wide ES assessments and the scale of individual property-level decisions. These issues warrant consideration by those involved in ES assessment and/or policy. Despite the challenges associated with using ES knowledge, the processes of the county-wide assessments did affect how decision-makers thought about longer-term, regional planning. And decision-makers appreciated having additional ways to communicate with people about the value of conservation.

A few factors could explain the different results between Santa Clara and Santa Cruz counties. ES knowledge can be expected to have different impacts on decision-makers within the varied cultures, as well as the different natural resource management approaches, of Santa Clara and Santa Cruz counties. Also, small differences existed in how and when the initiative was implemented in each county. The Santa Clara report on Nature's Value was completed two months before the Santa Cruz report and while

both counties underwent similar ES valuation studies, any two separate assessment processes could have inevitable differences.

Why did the pictures painted by our quantitative and qualitative analyses differ? For several outcomes with non-significant results, our interviewees discussed real changes in attitudes. We consider four possible rival explanations and posit how likely each is.

First, ES has been an increasingly popular topic in conservation, and other state or national ES programs could have influenced both comparison and treatment groups (reducing the influence of initiatives occurring in only our treatment counties). Since this spillover would equalize outcomes between groups, it is a likely explanation of some of the non-significant difference-in-differences results. Similarly, a spillover effect from treatment counties to nearby comparison counties could also have influenced our survey results. There were undoubtedly pre-existing relationships among people in the northern California conservation community.

Second, low sample size and selection bias likely obscured differences in our quantitative results. By the time we collected post-initiative data, we had a small sample size in our panel data that weakened our statistical tests. As in all such studies, our survey design (i.e. basic choice of outcomes to measure and wording of questions) introduced measurement error that could have made it difficult to detect impact (Bamberger, 2012). Also, the selection of decision-makers was based on identifying a target audience for the initiative and counterparts in comparison counties. Those individuals who completed both the pre- and post-initiative surveys were engaged enough to complete the surveys over the course of two years, and this selection bias would make the quantitative results non-significant if they did not report strong changes in understanding or attitudes pre/post.

Third, many of the initiative's impacts will take time to emerge and will be subtle, involving shifts in perspective and policy dialogue with respect to nature. Actual policy decisions and other potential ecological impacts are expected to occur beyond the timeframe of our study. Lastly, the quantitative results could mean the initiative did not make a detectable difference. This is unlikely as the interviews uncovered a growing understanding of ES and showed that decision-makers acquired insights into specific ways they could use ES knowledge to inform decisions.

By triangulating among qualitative and quantitative analyses, we found mixed methods provided a fuller evaluation of impact than either approach could alone (Smith et al., 2012; Spilsbury and Nasi, 2006). Using the survey with a comparison group allowed us to estimate what we would have observed had the initiative not occurred. Using interviews allowed us to directly ask decision-makers in interviews to comment on the hypothetical situation where no ES assessments had occurred. By estimating counterfactual situations with a comparison group and through interviews, we can tentatively link observed impacts on decision-makers to the initiative.

The conservation community would benefit from more rigorous impact assessment of ES projects. Future research with longer-term monitoring could contribute to understanding the full chain of impact: from scientific analyses and the knowledge they generate (i.e. interventions), to changes in the understanding and attitudes of decision-makers, altered policies or plans, and ultimately actual improved outcomes for ES and human well-being. Multi-site evaluations with better estimates of counterfactuals (perhaps by statistical matching on observable characteristics) and randomized study designs are not always feasible, but should be the aim. Whatever the specific approach, ES projects should more often include impact evaluation as a core component, as the Healthy Lands, Healthy Economies Initiative has. This would improve our understanding of how knowledge links to impact and benefit the design of future ES conservation programs.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2016.06.003.

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