The social structure of climate change research and practitioner engagement: Evidence from California[1,2]

Zeke Baker* [a,b,c], **Julia A. Ekstrom**[c,d], **Kelsey D. Meagher**[c,e], **Benjamin L. Preston**[f], **Louise Bedsworth**[g]

[a] National Oceanic and Atmospheric Administration, National Weather Service, Anchorage, AK, USA
[b] University of Oklahoma, Cooperative Institute for Mesoscale Meteorological Studies, Norman, OK, USA
[c] University of California Davis, Policy Institute for Energy, Environment and the Economy, Davis, CA, USA
[d] California Department of Water Resources, Sacramento, CA, USA
[e] University of California Davis, Department of Food Science and Technology, Davis, CA, USA
[f] RAND Corporation, Santa Monica, CA, USA
[g] California Strategic Growth Council, Sacramento, CA, USA

*Direct correspondence to Zeke Baker, zeke.baker@noaa.gov, National Oceanic and Atmospheric Administration, National Weather Service Alaska Region, 222 West 7th Avenue, Room 517, Anchorage, AK 99513, USA.

Abstract

Interactions between researchers and practitioners can lead to the increased use of climate science in decision-making. Past studies on these interactions have focused on the information needs of decision-makers, but less is known about why and how climate researchers choose to engage with decision-makers. Understanding the experiences, beliefs and constraints on both sides of the 'knowledge-action gap' is critical for implementing robust climate adaptation strategies. This study thus examines the perspectives and experiences of researchers regarding practitioner engagement, drawing from an original survey of California's climate research community (N=991) and supplemental interviews. Given a history of support for climate research and climate change adaptation, analysis of the California case is useful as a means of characterizing the relationship between climate research and practitioner engagement. We find that most scientists want to engage more with practitioners but are constrained by several factors, including resource limitations and the challenge of building relationships. Additionally, we find that the level of interest and frequency of engagement with stakeholders varies significantly

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across academic disciplines. We demonstrate that building capacity within research organizations and integrating stakeholder engagement in funding criteria and professional development can help foster relationship-building between scientists and decision-makers. The analysis suggests that the social structure of climate research warrants further examination of the ways that climate researchers relate to practitioners at present.

Keywords
co-production; sociology of science; science production; climate change adaptation; climate services

1. Introduction

Despite major advances in scientific understanding of climate change and increasingly dire projections of the consequences of such changes, efforts to address climate change appear insufficient when compared to projected impacts (IPCC 2018, Masson-Delmotte, et al., 2018; Moser et al., 2017). Seeking to explain this "knowledge-action gap" (Kirchhoff et al., 2015b; O'Brien, 2013), scholars have examined the relationship between the production of climate change knowledge and its use by policy makers and resource managers (Buizer et al., 2016; Cash et al., 2006; Lemos, 2015; Lemos et al., 2014, 2012; McNie, 2007; Sarewitz and Pielke, 2007). This scholarship outlines that climate information may be most useful when it is "co-produced" by researchers and decision-makers. Analyses of a "co-production" paradigm, however, have primarily focused on the uptake of specific research products among information users, attending to how the receptivity to climate information is influenced by the social context in which decision-makers are embedded, their technical capacity, and their trust of information producers.

Regarding climate change researchers, less is known about how and why they engage practitioners and about the barriers or opportunities they may face in the process. Scholars working in Science & Technology Studies have shown that social forces shape how climate science is produced (Edwards, 2010; Mahony and Hulme, 2018), yet studies have insufficiently addressed researchers' activities, motivations, and views regarding engagement with practitioners (Lemos et al., 2018; Preston et al., 2015). One way to address this issue is to focus on co-produced or jointly produced climate knowledge projects (Kolstad et al., 2019; Hegger and Dieperink 2015). Another is to more broadly analyze the institutional context in which climate researchers operate. Our study therefore asks, what is the social structure of climate research, and how does this structure influence patterns of engagement with non-researchers? Understanding the social dynamics of climate science production can help those operating in the domains of research, climate services, and science policy adapt institutions to incentivize knowledge production that proactively shapes and responds to climate actions, policies, and decision-making (Barnes et al., 2013; Clark et al., 2016; McDonald et al., 2019).

To answer these questions, we created a database of research articles, conducted a survey of climate researchers (n=991), and conducted interviews with select climate researchers (n=13) in California. Our findings characterize the social structure of the climate research field, describe patterns of engagement among researchers, and explain the drivers of researchers' engagement and associated barriers. As a case study of research and engagement focused on climate change in California, this study allows us to understand the social dynamics within a specific geographic and governance context while opening lines of theory-building and analysis in comparative contexts. The paper concludes with recommendations for how this study contributes to a more robust social analysis of climate research that can help inform policies that foster effective relationship-building between scientists and decision-makers.

2. Literature Review

Existing studies have proposed several factors that explain why people who may benefit from climate information elect to use it or not. One significant factor is adequate social interaction between knowledge producers and users (Kristjanson et al., 2009; Lemos, 2015). This close interaction is in stark contrast to the traditional, top-down flow of climate information, which begins by producing greenhouse gas emission scenarios and making global climate projections that can inform regional projections and then impact assessments (e.g., KNMI'14, 2014, NCCS, 2018; Lowe et al., 2018), which can finally bring climate information into the decision-making context (Brown et al., 2012; Jones et al., 2016; Mastrandrea et al., 2010). The linear model of the science-to-action process includes limited opportunities for identifying the knowledge and needs of practitioners and for specifying how social relationships may best facilitate their accommodation (Rigg and Mason, 2018).

Empirical evidence shows that interactions among users and producers, who "co-produce" climate knowledge, tends to enhance information use (Lemos and Morehouse, 2005; Arnott et al., 2020). To clarify, we draw upon Ostrom (1996) and Jasanoff (2004) to define co-production as the collaborative development of knowledge among scientists/experts and practitioners who use the information produced to make public decisions. As Bremer et al. (2017:13) suggest, the concept of "co-production" forms a prism through which both "descriptive" and "normative" analytic lenses can gain perspective on the dynamic interplay of science, society, and climate (see also Lemos et al. 2018:722). Our study adopts a descriptive lens insofar as we empirically consider how the social relationships that comprise climate science matter for how climate is treated in non-research contexts. Yet our study also takes a normative stance, insofar as the knowledge-action gap implies that knowledge producers have roles and responsibilities for engaging practitioners, which social analysis can inform.

For the purposes of this study, we define *practitioners* as anyone invested in administrative, managerial, and/or policy action regarding the impacts of climate change. Studies of co-produced research projects (Bidwell et al., 2013; Briley et al., 2015; Preston et al., 2015; Vogel et al., 2016) find that a co-production approach to producing knowledge is especially effective in the uncertain and often politically charged context of climate-related resource management, but it remains energy-intensive, financially expensive, and requires long-term investment from both practitioners and scientists. As an alternative to direct, sustained, or iterative relationships that characterize deliberate co-production, knowledge brokers and boundary organizations, specifically in the domain of "climate services," can be useful conduits through which researchers and practitioners can exchange knowledge and address societal needs (Flagg and Kirchhoff, 2018; Kirchhoff et al., 2015a, 2015b; Meyer et al., 2015; Vaughan et al., 2018). However, work on boundary organizations and climate services demonstrates that changes in scientific research and in management priorities are not always sufficiently communicated, especially when climate services are static products, for example web-based tools that lack built-in feedback processes. Porter and Dessai (2017) suggest that boundary objects may facilitate engagement or else serve, paradoxically, as a "firewall" that allows researchers to maintain distance and idealize users collectively as a technically competent "mini-me" of researchers. Clearly, as Porter and Dessai (2017:13) argue, "institutional constraints for doing science differently" still need to be addressed.

Engagement between climate research and action, including via deliberate co-production in climate adaptation settings, holds demonstrable value for researchers and practitioners (Hegger and Dieperink 2015; Brugger et al., 2015). The question of how to best configure scientific institutions with respect to that value can be addressed by an empirical understanding of the contemporary structure of science and engagement, akin to what Vaughan et al. (2018) consider a "bird's eye view" (in their case, of the unsettled meaning of climate services). The social study of climate science is beset by the fact that social data on climate science as a field has yet to be systematically collected. It follows that scholarly work has been limited in examining the perspectives of climate researchers in relation to the co-production process (Ernst et al., 2017, 2019; Ultee et al., 2018). This study helps fill this gap by examining original survey data on researchers' motivations, involvement, and perceived barriers to engaging with practitioners in producing climate change information relevant to decision-making. By approaching research engagement as a "social fact," that is, a phenomenon above its individual manifestations (Durkheim, 1982), those invested in bridging the "knowledge-action gap" can proceed on a more informed basis.

Climate Change Research and California

Climate assessment processes and government-sponsored partnerships clearly shape climate researchers' activity and engagement with practitioners ranging from local to international scales. This study focuses on climate change research in California because the state exhibits a long history of climate change research (Anderson et al., 2008; Franco et al., 2008), progressive climate action, and growing formal adaptation and resilience efforts (Bedsworth and Hanak, 2013; Ekstrom and Moser 2014; Moser et al., 2017; Shi et al., 2015). California completed its first state-funded comprehensive climate change assessment in 2006 and released its fourth assessment in 2018 that included both state- and externally-funded technical studies (Bedsworth et al., 2018). California's assessment results are designed to explicitly inform the state's climate policy (Franco et al., 2014). Although assessments, government-supported research, and science-based climate policy-making are common in other contexts, California provides a logical scale for analyzing existing and possible "co-production" arrangements because of the significant relationships already established between climate research and public decision-making.

2. Methods

The study has three goals:

1. Characterize the climate change research field in California, based on a survey of researchers;
2. Examine the engagement of climate change researchers with practitioners; and
3. Identify what constrains and facilitates researchers to engage with practitioners.

2.1 Survey

The research is based on a survey we designed and distributed to 3,000 researchers who have contributed to California's climate change assessments or produced relevant publications. To create the sampling frame, we first systematically compiled scholarly, peer reviewed article publications to identify climate researchers working on topics relevant to California. We used Scopus, a database of research publications and authors, to compile publications and full lists of authors for each article. The unit of analysis for the sampling frame is therefore authors on academic articles, in which "climate change" and "California" were present in either the article title, abstract, or keywords. We limited the corpus to English-language articles published between 2001 and 2018 in the broad Scopus-defined fields of economics, engineering, business, energy, agriculture, earth sciences, medicine, environment (see the Supplement for the complete query and additional information regarding the survey methods). We parameterized the corpus in this manner, given Scopus' coverage, data limitations for accessing article-level metadata, and in order to obtain a large, reliable database of individuals that have conducted research related to climate change in California.

The search yielded 1873 total research articles, which we exported and reviewed to manually exclude irrelevant items. Through a review of the study's focus and its authors' affiliations, we excluded articles that appeared not to include analysis of climate change in California. (This included, for example, studies that use California's climate mitigation policies for comparative or illustrative purposes only.) We created a record of every author on each article. Selecting only the first or last authors would have likely biased our sample frame by selecting only more senior researchers. Using article metadata, we then located the most recent author affiliation and contact information. To those whose contact data could reliably be obtained through internet research, we distributed the survey via email using the survey software Qualtrics.

Analysis of the survey was completed in Stata 14.2. The descriptive results presented below characterize the field of climate research. We also present a regression analysis of engagement and scientific prestige on individual characteristics. Details about measurement and model specification for the regression analysis can be found in the Supplemental Information.

2.2 Interviews

Although surveys provide aggregate data about researchers, semi-structured interviews enable a complementary exploration of how individuals experience and understand their participation in climate change research and their engagement with practitioners. Interviewees were drawn from the sample frame of survey respondents. Through quota sampling, we invited researchers for interviews who, based on survey data, could be considered either "high" or "low" in their public engagement. Within these categories, we invited those with "high" and "low" prestige, as measured by (1) the individual's h-index score and (2) their status in our sample, measured by the occurrence count of their authorship in the full sampling frame of research articles. The h-index is a score based on the number of papers an individual has published and the number of citations their work has received (Hirsch, 2005; Moldwin and Liemohn, 2018). We also targeted researchers who differed on the basis of demographic characteristics (age, gender, and race), employment type, field of study, and geographic location. In total, we invited fifteen individuals for interviews and interviewed thirteen of them. At the time of interview, four interviewed researchers held primary affiliations outside California, although all interviewees conducted climate change research in the state. Although not a representative sample that would allow intra-group comparison, interviews allowed us to contextualize our quantitative findings within individuals' real-world circumstances and diverse lived experiences as researchers. Five interviews were conducted in person, two by Skype, and six by phone. Interviews lasted between 30 and 75 minutes.

After transcription, interviews were imported into Dedoose, a qualitative data analysis software. We developed an initial codebook to correspond to the interview schedule and the topics that organized the survey. An initial round of coding utilized first-order, or "parent," codes (Careers, Production, Engagement, Barriers, Adaptation/Vision, and Social Structure). Second- and third-order child codes were developed inductively during a second round of coding. Following coding, analysis proceeded inductively by writing analytic memos. Memos, attached to coded excerpts, full transcripts, and individual codes, were then organized into six broad categories, roughly corresponding to the coding scheme, which could then help us to interpret the quantitative analysis.

The results presented are based on survey responses (N=991) and the 13 supplemental interviews. We conducted the survey and interviews in Summer and Fall 2018.

3. Results

Results of the survey are presented below with associated interview findings. The findings are organized according to the study goals identified above.

3.1 Characterization of the Climate Research Field

Table 1 displays the mean characteristics of the survey sample (N = 991). Respondents were predominantly white, male, and educated at the Ph.D.-level. The majority of respondents were employed in academia, though a substantial share reported working in government. Although respondents may not be statistically representative of the population of climate change researchers in California or beyond, additional analysis showed that the research fields represented by respondents correspond closely to the fields covered by the full compilation of climate research articles from which we created the sampling frame (Figures S2 and S3).

Table 1. *Mean characteristics of the survey sample (N = 991).*

Age	
18–34 years old	8.6%
35–44 years old	27.7%
45–54 years old	25.1%
55–64 years old	23.5%
65 years or older	15.2%
Male	66.6%
Race	
White	84.6%
Hispanic	6.3%
Asian/Pacific Islander	7.8%
Other	1.3%
Most advanced degree	
Bachelor's	2.4%
Master's	8.5%
PhD	87.9%
Other doctorate	1.2%
Current employment	
Academic	64.6%

Government	20.0%
Non-profit	7.4%
Private sector/consulting	4.2%
Unemployed/out of labor force	3.7%
Current employment contract	
Salaried, full-time	72.8%
Salaried, part-time	2.5%
Grant-funded, salaried, full-time	10.7%
Grant-funded, contract-based	5.4%
Retired	5.3%
Student	1.5%
Self-employed	0.6%

Respondents' fields of research and degree of focus on climate change varied widely. Most respondents reported to have remained in their trained discipline (Supp Info). Sixty-nine percent of all respondents reported that their current field matches the field of their most advanced degree. The most prevalent research field in which respondents reported to work is ecology or environmental science (39%), followed by earth sciences (20%) and atmospheric science (13%) (see Fig. 1). Nearly half of respondents (47%) reported spending more than half of their time on climate change research. Notably, nearly 90% have either increased (53%) or maintained (33%) the amount of their research time spent on climate change over the past decade.

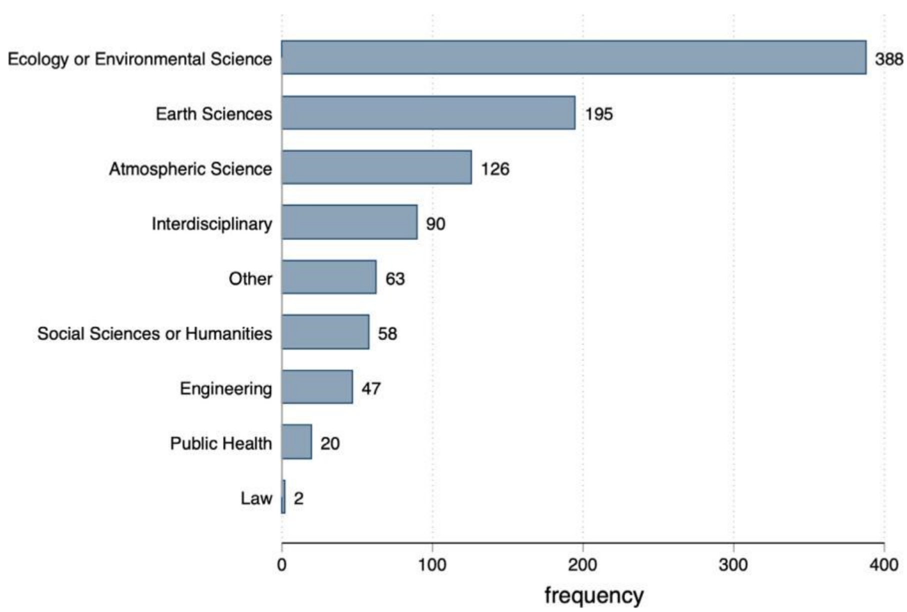

Figure 1. *Fields of research among survey respondents and Percent Time Spent on Climate Change Research (N=989).*

Survey respondents indicated that they most frequently conducted research on the following climate-related topics: climate hazards (53%), development of projections (28%), historical or paleoclimatology (27%), and sectoral impacts (27%). The smallest number of respondents conducted social science-related research (14%).

Nearly half of researchers reported that novel questions in their area of research have the greatest influence on the direction of their research focus, more so than departmental/organizational priorities (17%), follow-up from past research (10%), and available funding (10%) (Table 2).

Table 2. *First and second-most influential factors on research focus and direction*

	Primary influence No.	%	Secondary influence No.	%
Novel questions emerging in my area of research	422	44.9%	200	21.3%
My organization's or department's priorities	155	16.5%	83	8.8%
Funding availability	98	10.4%	174	18.5%
Answering questions based on my previous research	97	10.3%	252	26.8%
Needs of practitioners outside of my organization	86	9.1%	144	15.3%
Ability to publish in peer-reviewed journals	29	3.1%	65	6.9%
Other	54	5.7%	23	2.4%

Alongside respondents' reported demographic, employment and research characteristics, we also collected each respondent's h-index from Scopus to establish a proxy for scientific prestige, which may influence how researchers variously engage with practitioners. Respondents' h-index scores ranged widely, with the majority having low scores. This right-skewed distribution pattern was consistent across all respondents' research fields. However, on average, respondents in Atmospheric Sciences had a substantially higher h-index score than other fields, although this may be explained by publication frequencies or other differences across fields (Supp. Info.). Given the variation in the volume of citation across fields, we control for respondents' fields in all analyses of scientific prestige and practitioner engagement.

3.2 Engagement of Climate Researchers

This section presents survey results on the degree to which researchers engage with practitioners about their climate research. We examine potential differences in the frequency and nature of engagement across different fields, employment types, and demographic groups.

Most researchers expressed a strong interest in engaging practitioners, with only 18 percent of surveyed researchers reporting that they already engage as frequently as they would like. Overall, researchers reported interacting most frequently with other researchers, with nearly 70% interacting on a weekly basis, and much less frequently with other groups such as policy makers, the private sector, and non-profit organizations (mostly annually for ~35% of respondents) (Fig. 2).

To explore the factors that contribute to increased interaction between researchers and potential users of climate information, we conducted a regression analysis on the frequency of engagement. We scored each respondent's level of engagement across all non-research audiences to examine whether different factors explain higher or lower levels of engagement. (See Table 3).

Table 3. *OLS regression results for predictors of engagement and prestige, among academic and non-government samples*

	Outcome: engagement				Outcome: prestige (H-Index)			
	Academic sample		Non-government sample		Academic sample		Non-government sample	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Most advanced Degree (Bachelor's = base)								
Master's Degree	0.21	(0.41)	0.19	(0.27)	5.24	(6.99)	1.46	(4.70)
JD	0.24	(0.65)	0.33	(0.59)	9.34	(11.16)	5.16	(10.17)
PhD	−0.02	(0.38)	0.01	(0.26)	12.69+	(6.54)	9.10*	(4.43)
MD	−0.22	(0.85)	0.26	(0.47)	35.87*	(14.55)	16.54*	(8.15)
Other doctorate	−0.35	(0.53)	−0.28	(0.45)	7.68	(9.14)	3.49	(7.86)
Male	0.12+	(0.07)	0.08	(0.06)	2.90*	(1.19)	2.83	(1.09)
Age (18–34 years old = base)								
35–44 years old	0.44	(0.12)	0.43	(0.11)	4.37*	(2.01)	4.98	(1.85)
45–54 years old	0.57	(0.13)	0.59	(0.11)	12.35	(2.09)	11.93	(1.92)
55–64 years old	0.57	(0.13)	0.58	(0.12)	17.81	(2.08)	17.64	(1.94)
65+ years	0.51	(0.15)	0.51	(0.13)	22.04	(2.37)	22.04	(2.16)
Race (white = base)								
Hispanic	−0.07	(0.12)	−0.15	(0.11)	−5.62	(2.07)	−5.45	−1.9
Asian/Pacific Islander	−0.39	(0.12)	−0.36	(0.11)	−1.50	(2.04)	−2.98	−1.9
Other race	0.55+	(0.31)	0.59*	(0.25)	−4.62	(5.32)	−1.59	−4.37
Field (Atmospheric Science = base)								
Earth Sciences	0.10	(0.12)	0.14	(0.11)	−8.02	(1.97)	−8.61	(1.82)
Ecology or Environmental Science	0.20+	(0.11)	0.22*	(0.10)	−5.61	(1.78)	−7.37	(1.65)
Engineering	0.43	(0.16)	0.42	(0.16)	−8.34	(2.79)	−9.22	(2.69)
Public Health	0.72	(0.26)	0.52*	(0.23)	−3.73	(4.50)	−5.41	(4.01)
Social Sciences or Humanities	0.54	(0.16)	0.44	(0.15)	−14.67	(2.63)	−15.46	(2.47)
Interdisciplinary	0.40	(0.14)	0.36	(0.13)	−13.72	(2.33)	−15.15	(2.10)
Other	−0.10	(0.17)	−0.07	(0.15)	−10.18	(2.82)	−11.51	(2.52)
Prestige (H-index)	0.00	(0.00)	0.00	(0.00)	–	–	–	–
% Time on Climate Research (0% = base)								
Up to 25%	0.57*	(0.26)	0.39+	(0.23)	−9.07*	(4.42)	−4.45	(3.91)
>25–50%	0.66*	(0.26)	0.52*	(0.24)	−8.21+	(4.45)	−3.22	(3.94)
>50–75%	0.61*	(0.26)	0.41+	(0.24)	−6.36	(4.46)	−1.73	(3.96)
>75–100%	0.74	(0.26)	0.56*	(0.24)	−8.87*	(4.44)	−4.22	(3.93)
Employment sector (academic = base)								
Non-profit	–	–	0.55	(0.10)	–	–	−6.09	(1.75)
Private sector/consultant	–	–	0.30*	(0.13)	–	–	−1.39	(2.29)
Unemployed or out of labor force	–	–	−0.28+	(0.15)	–	–	−1.05	(2.59)
Constant	1.43	(0.47)	1.62	(0.37)	10.22	(8.05)	10.39+	(6.25)

Observations	560	694	563	698
R-squared	0.137	0.175	0.393	0.404

Standard errors in parentheses: P < 0.001. P < 0.01. P < 0.05, + P < 0.1.

Analysis shows that several factors are associated with higher levels of overall engagement. Age, race, current research field, and percent time focused on climate change are significant predictors of engagement. Engagement increases with age but declines after age 65. Asian/Pacific Islanders report significantly less engagement than whites and Hispanics. The more time researchers devote to climate change research, the more frequently they interact with non-academic groups. Respondents' gender, most advanced degree, and scientific prestige (measured as the respondent's h-index) are not significantly associated with engagement, after controlling for demographic characteristics. However, prestige and engagement are slightly positively correlated among academic respondents (r = .08), and many demographic characteristics are significant predictors of prestige, which suggests a potentially indirect relationship between prestige and the level of engagement (see Supp. Info.).

Notably, the frequency of engagement with non-researchers varies significantly across academic fields. Controlling for other individual characteristics, the fields with the highest levels of engagement are public health and the social sciences/humanities. The fields with the lowest levels of engagement are the earth and atmospheric sciences.

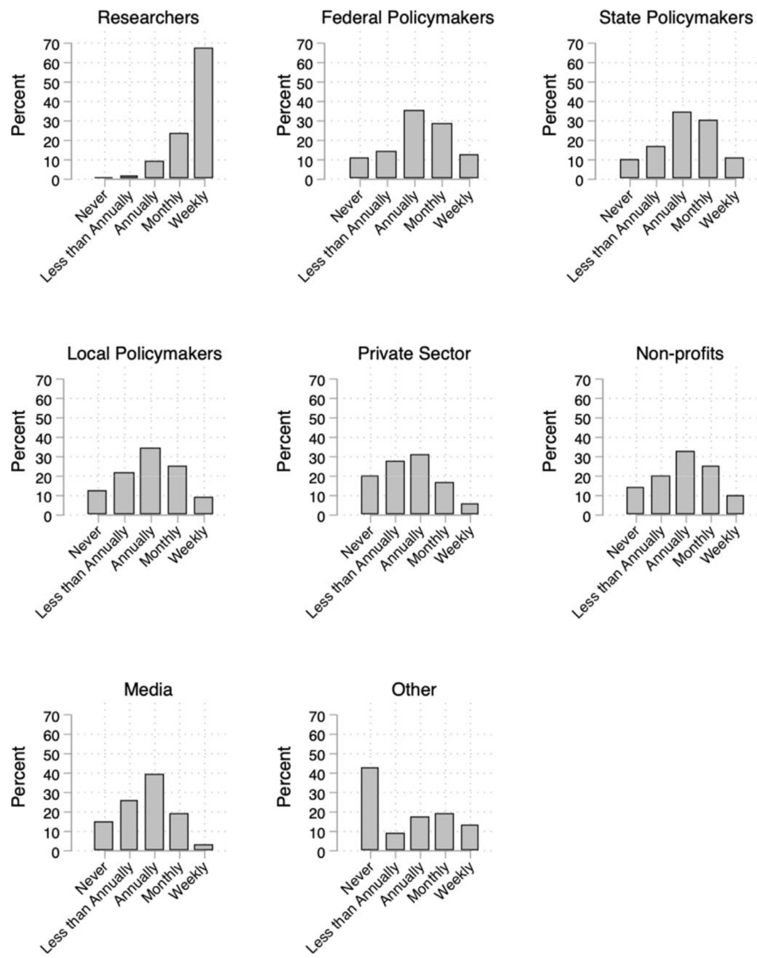

Figure 2. *Frequency of researchers' reported engagement with different audiences and/or collaborators (N=991).*

Interviews suggest that the frequency of engagement between researchers and practitioners is institutionally bounded. Respondents at federal agencies and university extension services described how their research is explicitly designed to engage stakeholders. For example, a major research program on sea level rise led by the US Geological Survey included specialized roles for outreach, and the researcher interviewed cited "weekly interactions with stakeholders" to help relevant practitioners use climate projections, offering a uniquely interactive and resource-demanding climate service. Without built-in outreach on research teams, academic researchers described the demands of teaching, professionally oriented research, and university service as institutional impediments to the engagement they acknowledged would benefit the uptake and relevance of their research. Researchers working outside academia (in consulting firms, non-profits, and federal agencies) expressed similar concern that professionally centered knowledge production is too removed from the needs of decision- makers. Comparing their work to previous academic experiences, one scientist at an international non-profit expressed the general sentiment, "Information means *nothing* if it has no vehicle for uptake." Other interviewees expressed similar frustrations, insofar as documented need for increased adaptation efforts often lack clear mechanisms to inspire research-informed action.

3.3 Barriers and Catalysts to Engagement

Under the paradigm that increased engagement is important to support societal climate adaptation processes, this section describes the barriers to engagement reported by climate change researchers.

The most frequently reported barriers to engagement are consistent with documented challenges of outreach among scientists more generally (Ecklund, James and Lincoln, 2012). In our survey, researchers most frequently reported “not enough time” (53%) and “it is challenging to establish relationships” (48%) as barriers to engagement (Figure 3a). The least-reported barrier (of those offered in the survey instrument) was lack of interest (3%). Although this result is likely biased by respondents’ self-selection into the survey, it clearly reinforces the finding of substantial interest among researchers in working with practitioners. Respondents who offered write-in answers regarding the primary barriers to engagement that they have experienced reflected the challenges of time and relationships (Figure 3b).

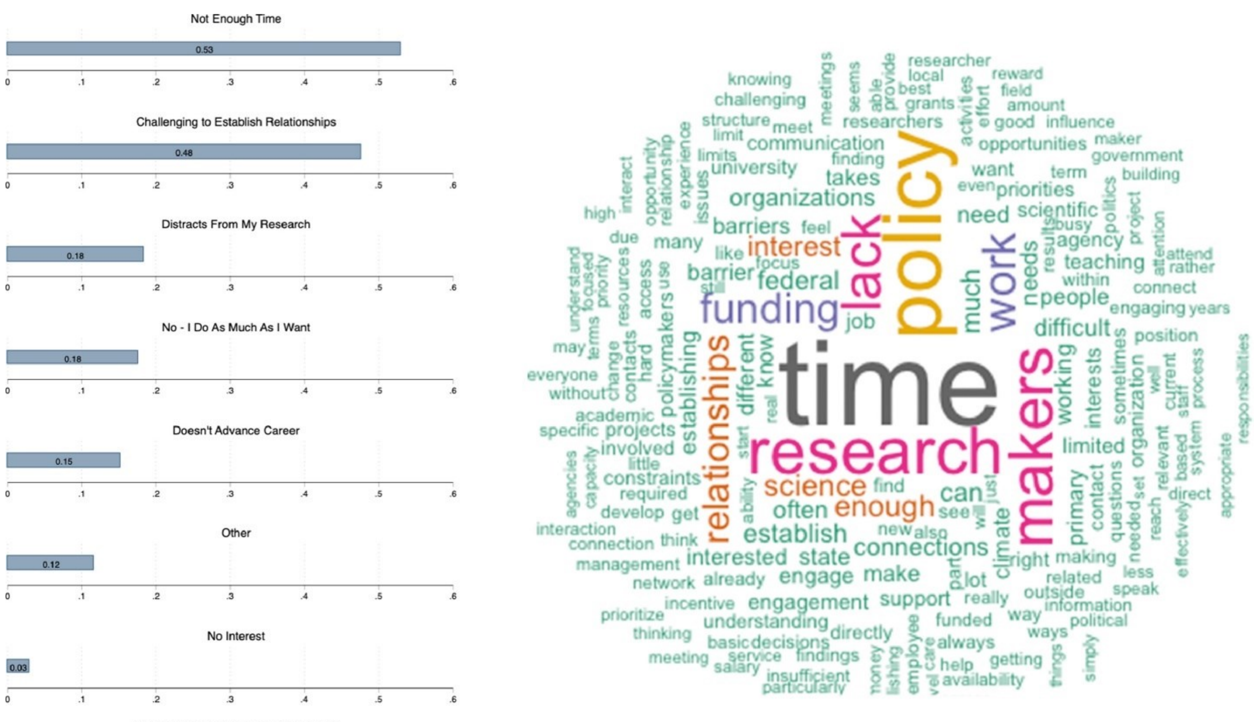

Figure 3. *Barriers to engagement, from (A - left) multiple choice selection question (n=966) and (B - right) word cloud of write-in responses of primary barrier to engagement reported by each climate researcher (n=747).*

To be actualized in public decision-making contexts, engaged research may face institutional constraints beyond not having enough time or a lack of established relationships. Findings broadly indicate that climate research is presently dominated by the fields of environmental and atmospheric sciences, although researchers across disciplines and employment types hold that the issue of climate change largely outstrips the boundaries of physical and natural science problems.

In addition to discussing resource-related and social barriers to engagement with practitioners, researchers in interviews expressed a critical attitude regarding the present pathways that translate research to practical action. One interviewee, a professor at a state university, posited that research is presently limited in informing public decision-making:

> "Science, at this point, can answer certain questions about climate change, but what's *not* happening is, there's not a clear connection for how you then actually get people to do it. I *don't* think that science is that important right now. I *don't* think that it's informing action…"

This view was upheld by others, including those whose research is highly engaged. As one scientist who works for a federal agency described:

> "The science is *really* good… But there's still a pretty big disconnect between the results and action … The projections aren't going to change that much, but we're missing something in a huge way in terms of how we connect to stakeholders and facilitate action and not just get people freaked out and no one [laughs] wants to *do* anything. Yeah, how do you do that?"

These interviewees reflect a general concern among researchers that knowledge about climate change (including their own research) holds ambiguous import for public decision-making. In the Discussion, we address the implications of this concern for facilitating researcher engagement.

4. Discussion

The survey results and supporting interviews offer notable insights regarding the social structure of climate change research in California. Below we discuss our findings with a focus on four major issues that hold implications for supporting effective engagement between researchers and practitioners. First is the pattern of engagement overall and across research fields. Second is the vision of engaged research that study participants exemplify. Third is the demographic and status composition of climate researchers, which may benefit from greater diversity. Fourth is how climate research institutions and related organizations may strategically overcome barriers to facilitate engagement in light of the present structure of the field.

4.1 An Engaged Science? Disciplinary Dynamics Matter

Expectedly, the overall field of climate change research is growing. Its proportional growth by research field is generally consistent over time. Based on respondents' educational backgrounds and current work fields, the over-representation of the physical sciences is expected given that it has long been the traditional anchor for climate change research (Collins et al., 2013; Shackley et al., 1998). Although many have called for the social sciences to inform adaptation efforts (Dunlap and Brulle, 2015; Hackmann et al., 2014; Victor, 2015), the field remains relatively light in the social sciences.

That the most highly engaged researchers are located in the social science/humanities disciplines most marginal in climate science (as indicated by their relative frequency in our corpus of climate science publications) means, in turn, that researchers in the fields most likely to produce climate-related research are also the least likely to engage with practitioners. Additional research is necessary to understand the field-specific social dynamics that are responsible for this disconnect. For example, our data show that climate researchers in the atmospheric and earth sciences are considerably older compared to researchers in the social sciences/humanities, engineering, and environmental/ecological sciences in our sample. This may reflect a shift in entry into climate change research by more human- and adaptation-centered disciplines. If patterns of engagement by age and field hold in the future, we would expect climate research overall to become a different, and perhaps more engaged, field. Yet the disciplinary structure of climate research may also proceed in a way that is shaped by its historical trajectory, that is, dominated by physical sciences despite longstanding pursuit of inter- and multi-disciplinary work (Schneider 1977; Shove, 2010).

4.2 The Limits of Science Present Opportunities for Prioritizing Engagement

Climate researchers care deeply about the future challenges that decision-makers face, meaning it is incorrect to characterize climate science as primarily invested in being "removed" from public concern regarding climate change. Interview participants, which included social, environmental, and physical scientists, echoed concerns about the future direction of scientific research and its relevance to what many see as a significant need for increased public action to mitigate and adapt to climate change. Surprisingly, even relatively high-prestige physical scientists discussed what they viewed as a deficiency of science produced at present, suggesting a need to further reflect on the character of research that should be bolstered for better supporting climate adaptation-related decisions.

One interviewee expressed a common view: “It’s really more about, like, ‘what do we want our world to look like and what do we value for maintaining the human species?’…Science, to me, has not clearly set itself up for answering these questions.” As another researcher put it, “For many of us that have been working in this field for 10, 15, 20 + years, it’s a bit like being an oncologist and self-diagnosing for cancer: you know what the stages are and that it’s going to get worse. Watching that unfold is difficult, right?” Notwithstanding pessimistic views or claims that climate adaptation is not a “scientific problem,” in practice, researchers reported acting on their sense of public responsibility through the means available to them. Such initiatives included building university programs that “get out of the silo of atmospheric science,” creating management tools that are co-produced with users, and conducting outreach that contributes expertise in climate impacts to local resource managers.

Willingness on the part of researchers to engage non-researchers, however, is clearly insufficient to overcoming barriers to the kinds of climate science many would like to see. Paralleling the quantitative finding of a gap between researchers’ level of engagement and willingness to engage practitioners, researchers in interviews invoke a sense of frustrated moral duty to their work, referencing topics that include remorse that scientific research cannot resolve “misery” of “millions of people”; recognition that they cannot control misinformation or confusing headlines regarding climate change impacts; and a national political context in which researchers view “scientific values” as being regularly surpassed by other values. These moral sentiments regarding science may indeed help to explain why our survey data show that the more time researchers devote to climate change research, the more frequently they interact with non-academic groups: as scientists come to “own” climate issues, their desire to engage society increases, a trajectory observable in recent acts of high-profile public action among scientists. Examples include utilizing scientific outlets to declare “climate emergency” (Ripple et al. 2019) and generate support for social movements (Gardner and Wordley 2019). How such actions reshape scientific practice and practitioner engagement remains to be seen.

In terms of routine work among researchers in our study, interviewees expressed a belief that engaged research is more desirable work. This belief held for those who reported overcoming barriers to pursuing engaged work as well as for those who report only minimal engagement with non-researchers. Lower-prestige, entry-level academic researchers are perhaps the most frustrated by the barriers to entry into meaningfully engaged research. Reporting limited resources and less job security, these researchers generally work in settings designed to incorporate students and research staff rather than those whom the research may purportedly benefit. Thus, the structure of climate research may not be meeting the vision of science and climate action that many researchers hold, a finding affirmed by literature on the barriers to engaged research (Ecklund, et al., 2012; Dilling and Lemos 2011). This finding may only be accentuated in other political contexts, insofar as researchers in this study generally viewed

California as a state that strongly supports climate research and limits the encroachment of partisan politics on research practices, which interviewees reported encountering elsewhere.

4.3 Demographic Diversity and Engagement

The content of climate research and the types of engagement pursued by and available to researchers may be shaped by the demographic and social status differences that characterize the climate science field. Our study indicates that the majority of climate-change researchers are white men. Interviewees provided evidence of discrimination on the basis of demographic characteristics, although further investigation is necessary to determine how the predominance of white men in the field shapes the opportunities and barriers faced by minority groups and the types of engagement generally pursued. Research on racial and gender stratification in academia and scientific fields (NSF, 2018; Harding, 2016; Milkman et al, 2015; Shauman, 2017; Smith-Doerr et al., 2017) has recently been applied to climate research in limited ways (Gay-Antaki and Liverman, 2018), reflecting longstanding issues of inequity in climate research and policy (Klinsky et al., 2017). This larger body of work suggests that the socio-demographic composition of research fields shapes the choice of research problems, the chances of researchers' career success, and the social orientation of researchers. Our analysis of climate research suggests that further inquiry should investigate, for example, a possible intersection between "epistemic exclusion" (Settles et al., 2018) within the climate research field and the kinds of knowledge that succeed or fail to inform practitioner engagement and climate action.

4.4 Activating Engaged Research through Public and Professional Support

Analysis of research fields and the social characteristics of climate researchers contributes to the body of literature on the supply, demand, co-production, and communication of climate information (Archie et al., 2014; Dilling and Lemos, 2011; Weaver et al., 2013). The emphasis in the adaptation literature on delivering climate information and services that can be used by practitioners to enable adaptation largely frames the issue as one of meeting the perceived demand for information, a finding generally concluded on the basis of case studies of co-production in action (Vogel et al., 2016; Briley et al., 2015). Complementary to case studies, which document barriers to successful co-production, we find that broader institutional factors constrain how researchers may relay their research practices into engaged relationships with practitioners.

In particular, our findings indicate that even in situations of user demand for climate information, barriers on the production side to building engaged relationships between researchers and practitioners limit the ability of the research community to facilitate climate action. Changes to the incentives for researchers to engage with practitioners could accelerate the flow of climate information to adaptation practice. Our survey and interview findings further suggest that the pursuits of scientific prestige, career advancement and engagement may be complementary rather than opposed. Although the relationship between scientific prestige and practitioner engagement requires further study, what may be required is participation by other actors (such as philanthropies, government, non-profits, and other user communities) who can provide funding and related resources to support relationships between climate science producers and relevant user groups (Arnott et al., 2020; Cundill et al., 2019; Ultee et al., 2018).

More players entering the domain of climate services, however, raises additional issues of coordination and credibility. On the one hand, interviewees suggested that private contracting firms and non-profit organizations provide critical specialized services that engage practitioners more effectively than academic researchers. On the other hand, some worried that private interests do not adequately present practitioners with the best available science, an issue that may be allayed through working relationships between private actors, NGOs, and researchers within a more codified or standard organization of "climate services." Yet Vaughan et al. (2018) find many climate services internationally involve the creation of web-based services that often neither function with specific user groups in mind nor involve users in the co-production of climate information.

The proliferation of climate services may be only partly driven by specific user demands, and more by the growing field of climate knowledge production among specialized research firms, including publicly funded services but also commercial/contracting firms that more generally operate on a market logic (Lave 2015). This situation for the knowledge economy opens up a clear role for public resources to support researcher-practitioner coordination and grant credibility to climate service programs. For example, the US National Oceanic and Atmospheric Administration, a major producer of climate information, has shifted priorities in some branches towards providing "decision support services" that directly integrate public sector practitioners and researchers, often using a rigorous protocol to ensure services meet practitioner needs (NOAA 2016; NOAA 2019). These efforts are mirrored in NOAA's Regional Integrated Sciences and Assessments (RISA) program, involving partnerships between agency expertise, researchers, and resource managers (Lemos et al., 2014).

As for the primary barriers of time and difficulty establishing relationships with practitioners, our research suggests that funding incentives, for example the inclusion of practitioner engagement as a grant criterion, could activate what we found to be researchers' generally strong willingness for engagement, a position supported by longitudinal research on funding criteria performed by Arnott et al. (2020). If frequent interactions between researchers and users can indeed strengthen climate adaptation efforts, our results indicate that addressing researchers' resource barriers has a high potential for supporting such interactions. Lack of time and capacity for engaging practitioners is compounded by other scarce resources, including alternative work activities that researchers believe may advance their careers. Given attacks on federal support for climate research in the US (Sabin Center 2019), coupled with the international pattern toward precarious academic employment (Fischer and Mandell 2018), there may be a new role for professional organizations in building relationships between scientists and practitioners (e.g., the American Geophysical Union's Thriving Earth Exchange). Professional organizations may serve the critical role of formally valorizing engaged research, especially by integrating junior and minority researchers and providing avenues for publication and recognition that generate the prestige required for career advances in research organizations. This may partly overcome barriers that at present characterize climate change research in government and university settings, which in our study hold the vast majority of researchers.

As an initial exploration of the climate change research field and its engagement with practitioners, our inquiry generates more questions than it answers. First, our study focuses only on researchers who have produced work related to California. The survey instrument could be used to establish comparative accounts of the climate research field and of the drivers and predictors of practitioner engagement. Is California-focused climate change research unique in its demographics, or are other Western contexts more or less diverse? Does the presence of a major state academic system change the distribution of disciplines that characterize climate change research? How much does state support for climate change research impact the frequency and extent to which researchers engage practitioners? Does the level of support for (or perceived risks attached to) engaging public actors on climate change issues increase or decrease researchers' motivations to engage? These questions can build upon the methods and findings of our study, but they require multiple data sources and analysis across other additional cases.

5. Conclusion

As social actors advance activities to anticipate and adapt to the impacts of climate change, the scientific field should also be evaluated on whether it addresses the changing spectrum of public and societal needs. This requires attention not only to climate information as such, but also to researchers as socially embedded actors (Preston et al., 2015). Reflecting on the social composition, engagement, and barriers of those participating in the climate research field, as initiated here, can inform the development and evaluation of climate services and co-production efforts. Taking the pulse of the producers of climate change research offers an entry point to develop supportive institutional structures for co-production and climate services that leverage researchers' desire to engage while also recognizing the material and institutional barriers that researchers face.

The trajectory of climate research and engagement between researchers and practitioners is a structural one—a "social fact" that is never reducible to an individual instance, successful or otherwise, of how researchers have co-produced actionable climate information alongside decision-makers. Examples of such efforts are remarkable and hold lessons for research teams and organizations that create, provide and use climate information. Nevertheless, given the gravity of climate-change issues, the ongoing growth of climate science, and the persistent "knowledge-action" gap (O'Brien, 2013), our study contributes to a perspective, echoed by many of our research respondents, that the general character of climate research at present must be restructured to more directly embrace the issues and decisions that characterize our climate change-impacted society. In a situation when researchers desire practitioner engagement, significant time, financial resources, and capacity-building must be reallocated so that co-production may proceed in ways that benefit, rather than hinder, all of those involved. The disciplinary, demographic, and organizational composition of the climate research field must continue to be critically examined so as to coproduce the best possible science that can inform and reflexively respond to those taking public action on climate change.

References

Anderson, J., Chung, F., Anderson, M., Brekke, L., Easton, D., Ejeta, M., Peterson, R., Snyder, R., 2008. Progress on incorporating climate change into management of California's water resources. Climatic Change 87, 91–108. https://doi.org/10.1007/s10584-007-9353-1

Archie, K.M., Dilling, L., Milford, J.B., Pampel, F.C., 2014. Unpacking the 'information barrier': Comparing perspectives on information as a barrier to climate change adaptation in the interior mountain West. Journal of Environmental Management 133, 397–410. https://doi.org/10.1016/j.jenvman.2013.12.015

Arnott, J.C., Neuenfeldt, R.J., Lemos, M.C., 2020. Co-producing science for sustainability: Can funding change knowledge use? Global Environmental Change 60, 101979. https://doi.org/10.1016/j.gloenvcha.2019.101979

Barnes, J., Dove, M., Lahsen, M., Mathews, A., McElwee, P., McIntosh, R., Moore, F., O'Reilly, J., Orlove, B., Puri, R., Weiss, H., Yager, K., 2013. Contribution of anthropology to the study of climate change. Nature Climate Change 3, 541–544. https://doi.org/10.1038/nclimate1775

Bedsworth, L., Cayan, D., Franco, G., Fisher, L., Ziaja, S., 2018. Statewide Summary Report: California's Fourth Climate Change Assessment (No. SUMCCCA4-2018– 013). California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission.

Bedsworth, L.W., Hanak, E., 2013. Climate policy at the local level: Insights from California. Global Environmental Change 23, 664–677. https://doi.org/10.1016/j.gloenvcha.2013.02.004

Bidwell, D., Dietz, T., Scavia, D., 2013. Fostering knowledge networks for climate adaptation. Nature Climate Change 3, 610–611. https://doi.org/10.1038/nclimate1931

Bremer, S., Meisch, S., 2017. Co-production in climate change research: Reviewing different perspectives. Wiley Interdisciplinary Reviews: Climate Change 8, e482. https://doi.org/10.1002/wcc.482
Briley, L., Brown, D., Kalafatis, S.E., 2015. Overcoming barriers during the co-production of climate information for decision-making. Climate Risk Management, Boundary Organizations 9, 41–49. https://doi.org/10.1016/j.crm.2015.04.004
Brown, C., Ghile, Y., Laverty, M., Li, K., 2012. Decision scaling: Linking bottom-up vulnerability analysis with climate projections in the water sector. Water Resources Research 48. https://doi.org/10.1029/2011WR011212
Brugger, J., Meadow, A., Horangic, A., 2015. Lessons from first-generation climate science integrators. Bull. Amer. Meteor. Soc. 97, 355–365. https://doi.org/10.1175/BAMS-D-14-00289.1
Buizer, J., Jacobs, K., Cash, D., 2016. Making short-term climate forecasts useful: Linking science and action. Proceedings of the National Academy of Sciences 113, 4597–4602. https://doi.org/10.1073/pnas.0900518107
Cash, D.W., Borck, J.C., Patt, A.G., 2006. Countering the loading-dock approach to linking science and decision making: Comparative analysis of El Niño/Southern Oscillation (ENSO) forecasting systems. Science, Technology & Human Values 31, 465–494. https://doi.org/10.1177/0162243906287547
Clark, W.C., Kerkhoff, L. van, Lebel, L., Gallopin, G.C., 2016. Crafting usable knowledge for sustainable development. Proceedings of the National Academy of Sciences 113, 4570–4578. https://doi.org/10.1073/pnas.1601266113
Collins, M., Knutti, R., Arblaster, J., Dufresne, J.-L., Fichefet, T., Friedlingstein, P., Gao, X., Gutowski, W.J., Johns, T., Krinner, G., Shongwe, M., Tebaldi, C., Weaver, A.J., Wehner, M., 2013. Chapter 12 - Long-term climate change: Projections, commitments and irreversibility, in: IPCC (Ed.), Climate Change 2013: The Physical Science Basis. IPCC Working Group I Contribution to AR5. Cambridge University Press, Cambridge.
Cundill, G., Currie-Alder, B., Leone, M., 2019. The future is collaborative. Nature Climate Change 1. https://doi.org/10.1038/s41558-019-0447-3
Dilling, L., Lemos, M.C., 2011. Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. Global Environmental Change 21, 680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006
Dunlap, R.E., Brulle, R.J., 2015. Climate Change and Society: Sociological Perspectives. Oxford University Press.
Durkheim, E., 1982. What is a Social Fact?, in: Durkheim, E., Lukes, S. (Eds.), The Rules of Sociological Methodand Selected Texts on Sociology and Its Method. Macmillan Education UK, London, pp. 50–59. https://doi.org/10.1007/978-1-349-16939-9_2
Ecklund, E.H., James, S.A., Lincoln, A.E., 2012. How academic biologists and physicists view science outreach. PLOS ONE 7, e36240. https://doi.org/10.1371/journal.pone.0036240
Edwards, P.N., 2010. A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming. MIT Press, Cambridge, MA.
Ekstrom, J.A. and S.C. Moser. 2014. Identifying and overcoming barriers in urban climate adaptation: Case study findings from the San Francisco Bay Area, California, USA. Urban Climate 9:54-74. https://doi.org/10.1016/j.uclim.2014.06.002

Ernst, K., Preston, B.L., Tenggren, S., Klein, R., Gerger-Swartling, Å., 2017. Examining Challenges Related to the Production of Actionable Climate Knowledge for Adaptation Decision-Making: A Focus on Climate Knowledge System Producers. AGU Fall Meeting Abstracts 41.
Ernst, K.M., Swartling, Å.G., André, K., Preston, B.L., Klein, R.J.T., 2019. Identifying climate service production constraints to adaptation decision-making in Sweden. Environmental Science & Policy 93, 83–91. https://doi.org/10.1016/j.envsci.2018.11.023
Fischer, F., Mandell, A., 2018. The neo-liberal transformation of the university. Critical Policy Studies 12, 103–103. https://doi.org/10.1080/19460171.2018.1441942
Flagg, J.A., Kirchhoff, C.J., 2018. Context matters: Context-related drivers of and barriers to climate information use. Climate Risk Management 20, 1–10. https://doi.org/10.1016/j.crm.2018.01.003
Franco, G., Bedsworth, L., Pairis, A., 2014. California's Comprehensive Approach to Climate Change: The Pivotal Role of Research. EM June 2014, 20-23.
Franco, G., Cayan, D., Luers, A., Hanemann, M., Croes, B., 2008. Linking climate change science with policy in California. Climatic Change 87, 7–20. https://doi.org/10.1007/s10584-007-9359-8
Gay-Antaki, M., Liverman, D., 2018. Climate for women in climate science: Women scientists and the Intergovernmental Panel on Climate Change. Proceedings of the National Academy of Sciences 115, 2060. https://doi.org/10.1073/pnas.1710271115
Hackmann, H., Moser, S.C., Clair, A.L.S., 2014. The social heart of global environmental change. Nature Climate Change 4, 653–655. https://doi.org/10.1038/nclimate2320
Harding, S., 2016. Whose Science? Whose Knowledge?: Thinking from Women's Lives. Cornell University Press, Ithaca, NY.
Hegger, D., Dieperink, C., 2015. Joint knowledge production for climate change adaptation: what is in it for science? Ecology and Society 20. https://doi.org/10.5751/ES-07929-200401
Hirsch, J.E., 2005. An index to quantify an individual's scientific research output. Proceedings of the National Academy of Sciences 102, 16569–16572. https://doi.org/10.1073/pnas.0507655102
IPCC, Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T., 2018. Global warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways.
Jasanoff, S. (Ed.), 2004. States of Knowledge: The Co-production of Science and the Social Order. Routledge, London.
Jones, A., Calvin, K., Lamarque, J.-F., 2016. Climate modeling with decision makers in mind. Eos, Transactions of the American Geophysical Union (Online) 97. https://doi.org/10.1029/2016EO051111
Kirchhoff, C.J., Esselman, R., Brown, D., 2015a. Boundary organizations to boundary chains: Prospects for advancing climate science application. Climate Risk Management 9, 20–29. https://doi.org/10.1016/j.crm.2015.04.001

Kirchhoff, C.J., Lemos, M.C., Kalafatis, S., 2015b. Narrowing the gap between climate science and adaptation action: The role of boundary chains. Climate Risk Management 9, 1–5. https://doi.org/10.1016/j.crm.2015.06.002

Klinsky, S., Roberts, T., Huq, S., Okereke, C., Newell, P., Dauvergne, P., O'Brien, K., Schroeder, H., Tschakert, P., Clapp, J., Keck, M., Biermann, F., Liverman, D., Gupta, J., Rahman, A., Messner, D., Pellow, D., Bauer, S., 2017. Why equity is fundamental in climate change policy research. Global Environmental Change 44, 170–173. https://doi.org/10.1016/j.gloenvcha.2016.08.002

KNMI'14, 2014. Climate Change scenarios for the 21st Century – A Netherlands perspective. Scientific Report WR2014-01, KNMI, De Bilt, The Netherlands. www.climatescenarios.nl

Kolstad, E.W., Sofienlund, O.N., Kvamsås, H., Stiller-Reeve, M.A., Neby, S., Paasche, Ø., Pontoppidan, M., Sobolowski, S.P., Haarstad, H., Oseland, S.E., Omdahl, L., Waage, S., 2019. Trials, Errors, and Improvements in Coproduction of Climate Services. Bull. Amer. Meteor. Soc. 100, 1419–1428. https://doi.org/10.1175/BAMS-D-18-0201.1Kristjanson, P., Reid, R.S., Dickson, N., Clark, W.C., Romney, D., Puskur, R., MacMillan, S., Grace, D., 2009. Linking international agricultural research knowledge with action for sustainable development. Proceedings of the National Academy of Sciences 106, 5047. https://doi.org/10.1073/pnas.0807414106

Lave, R., 2015. The future of environmental expertise. Annals of the Association of American Geographers 105, 244–252. https://doi.org/10.1080/00045608.2014.988099

Lemos, M.C., 2015. Usable climate knowledge for adaptive and co-managed water governance. Current Opinion in Environmental Sustainability 12, 48–52. https://doi.org/10.1016/j.cosust.2014.09.005

Lemos, M.C., Arnott, J.C., Ardoin, N.M., Baja, K., Bednarek, A.T., Dewulf, A., Fieseler, C., Goodrich, K.A., Jagannathan, K., Klenk, N., Mach, K.J., Meadow, A.M., Meyer, R., Moss, R., Nichols, L., Sjostrom, K.D., Stults, M., Turnhout, E., Vaughan, C., Wong-Parodi, G., Wyborn, C., 2018. To co-produce or not to co-produce. Nature Sustainability 1, 722–724. https://doi.org/10.1038/s41893-018-0191-0

Lemos, M.C., Kirchhoff, C.J., Kalafatis, S.E., Scavia, D., Rood, R.B., 2014. Moving climate information off the shelf: Boundary chains and the role of RISAs as adaptive organizations. Weather, Climate, and Society 6, 273–285. https://doi.org/10.1175/WCAS-D-13-00044.1

Lemos, M.C., Kirchhoff, C.J., Ramprasad, V., 2012. Narrowing the climate information usability gap. Nature Climate Change 2, 789–794. https://doi.org/10.1038/nclimate1614

Lemos, M.C., Morehouse, B.J., 2005. The co-production of science and policy in integrated climate assessments. Global Environmental Change 15, 57–68. https://doi.org/10.1016/j.gloenvcha.2004.09.004

Lowe, J. A., et al, 2018: UKCP18 Science Overview Report, November 2018, https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Overview-report.pdf

Mahony, M., Hulme, M., 2018. Epistemic geographies of climate change: Science, space and politics. Progress in Human Geography 42, 395–424. https://doi.org/10.1177/0309132516681485

Mastrandrea, M.D., Heller, N.E., Root, T.L., Schneider, S.H., 2010. Bridging the gap: linking climate-impacts research with adaptation planning and management. Climatic Change 100, 87–101. https://doi.org/10.1007/s10584-010-9827-4

McDonald, K.S., Hobday, A.J., Thompson, P.A., Lenton, A., Stephenson, R.L., Mapstone, B.D., Dutra, L.X.C., Bessey, C., Boschetti, F., Cvitanovic, C., Bulman, C.M., Fulton, E.A., Moeseneder, C.H., Pethybridge, H., Plagányi, E.E., Putten, E.I. van, Rothlisberg, P.C., 2019. Proactive, Reactive, and Inactive Pathways for Scientists in a Changing World. Earth's Future 7, 60–73. https://doi.org/10.1029/2018EF000990

McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature. Environmental Science & Policy 10, 17–38. https://doi.org/10.1016/j.envsci.2006.10.004

Meyer, R., McAfee, S., Whiteman, E., 2015. How California is mobilizing boundary chains to integrate science, policy and management for changing ocean chemistry. Climate Risk Management 9, 50–61. https://doi.org/10.1016/j.crm.2015.04.002

Milkman, K.L., Akinola, M., Chugh, D., 2015. What happens before? A field experiment exploring how pay and representation differentially shape bias on the pathway into organizations. J. Appl. Psychol. 100, 1678–1712. https://doi.org/10.1037/ apl0000022.

Moldwin, M.B., Liemohn, M.W., 2018. High-Citation papers in space physics: Examination of gender, country, and paper characteristics. Journal of Geophysical Research: Space Physics 123, 2557–2565. https://doi.org/10.1002/2018JA025291

Moser, S.C., Coffee, J., Seville, A., 2017. Rising to the Challenge, Together: A Review and Critical Assessment of the State of the US Climate Adaptation Field. A Report Prepared for The Kresge Foundation.

National Oceanic and Atmospheric Administration (NOAA), 2016. NOAA water initiative. https://www.noaa.gov/sites/default/files/atoms/files/NOAA_Water_Initiative%20Plan-final-12202016.pdf

National Oceanic and Atmospheric Administration (NOAA), 2019. National Weather Service strategic plan, 2019-2022. https://www.weather.gov/media/wrn/NWS_Weather-Ready-Nation_Strategic_Plan_2019-2022.pdf

National Science Foundation (NSF), 2018. Women and minorities in the S&E workforce, In: National Science Board Science and Engineering Indicators, 2018. https://www.nsf.gov/statistics/2018/nsb20181/report/sections/science-and-engineering-labor-force/women-and-minorities-in-the-s-e-workforce

NCCS, 2018. CH2018 - Climate Scenarios for Switzerland. National Centre for Climate Services, Zurich.

O'Brien, K., 2013. Global environmental change III: Closing the gap between knowledge and action. Progress in Human Geography 37, 587–596. https://doi.org/10.1177/0309132512469589

Ostrom, E., 1996. Crossing the great divide: Coproduction, synergy, and development. World Development 24, 1073–1087. https://doi.org/10.1016/0305-750X(96)00023-X

Porter, J.J., Dessai, S., 2017. Mini-me: Why do climate scientists' misunderstand users and their needs? Environmental Science & Policy 77, 9–14. https://doi.org/10.1016/j.envsci.2017.07.004

Preston, B.L., Rickards, L., Fünfgeld, H., Keenan, R.J., 2015. Toward reflexive climate adaptation research. Current Opinion in Environmental Sustainability, Open Issue 14, 127–135. https://doi.org/10.1016/j.cosust.2015.05.002
Rigg, J., Mason, L.R., 2018. Five dimensions of climate science reductionism. Nature Climate Change 8, 1030. https://doi.org/10.1038/s41558-018-0352-1
Ripple, W.J., Wolf, C., Newsome, T.M., Barnard, P., Moomaw, W.R., 2019. World scientists' warning of a climate emergency. BioScience. https://doi.org/10.1093/biosci/biz088
Sabin Center for Climate Change Law, 2019. Science silencing tracker. https://climate.law.columbia.edu/content/about-silencing-science-tracker
Schneider, S.H., 1977. Climate change and the world predicament: A case study for interdisciplinary research. Climatic Change 1, 21–43.
Sarewitz, D., Pielke, R.A., 2007. The neglected heart of science policy: Reconciling supply of and demand for science. Environmental Science & Policy, Reconciling the Supply of and Demand for Science, with a Focus on Carbon Cycle Research 10, 5–16. https://doi.org/10.1016/j.envsci.2006.10.001
Settles, I.H., Buchanan, N.T., Dotson, K., 2018. Scrutinized but not recognized: (In)visibility and hypervisibility experiences of faculty of color. Journal of Vocational Behavior. https://doi.org/10.1016/j.jvb.2018.06.003
Shackley, S., Young, P., Parkinson, S., Wynne, B., 1998. Uncertainty, complexity and concepts of good science in climate change modelling: Are GCMs the best tools? Climatic Change 38, 159–205. https://doi.org/10.1023/A:1005310109968
Shauman, K.A., 2017. Gender differences in the early employment outcomes of STEM doctorates. Social Sciences 6, 24. https://doi.org/10.3390/socsci6010024
Shi, L., Chu, E., Debats, J., 2015. Explaining progress in climate adaptation planning across 156 U.S. municipalities. Journal of the American Planning Association 81, 191–202. https://doi.org/10.1080/01944363.2015.1074526
Shove, E., 2010. Beyond the ABC: Climate change policy and theories of social change. Environ Plan A 42, 1273–1285. https://doi.org/10.1068/a42282
Smith-Doerr, L., Alegria, S.N., Sacco, T., 2017. How diversity matters in the US science and engineering workforce: A critical review considering integration in teams, fields, and organizational contexts. Engaging Science, Technology, and Society 3, 139–153. https://doi.org/10.17351/ests2017.142
Ultee, L., Arnott, J.C., Bassis, J., Lemos, M.C., 2018. From ice sheets to main streets: Intermediaries connect climate scientists to coastal adaptation. Earth's Future 6, 299–304. https://doi.org/10.1002/2018EF000827
Vaughan, C., Dessai, S., Hewitt, C., 2018. Surveying climate services: What can we learn from a bird's-eye view? Weather, Climate, and Society 10, 373–395. https://doi.org/10.1175/WCAS-D-17-0030.1
Victor, D., 2015. Climate change: Embed the social sciences in climate policy. Nature News 520, 27. https://doi.org/10.1038/520027a
Vogel, J., McNie, E., Behar, D., 2016. Co-producing actionable science for water utilities. Climate Services 2–3, 30–40. https://doi.org/10.1016/j.cliser.2016.06.003
Weaver, C.P., Lempert, R.J., Brown, C., Hall, J.A., Revell, D., Sarewitz, D., 2013. Improving the contribution of climate model information to decision making: The value and demands of

robust decision frameworks. Wiley Interdisciplinary Reviews: Climate Change 4, 39–60. https://doi.org/10.1002/wcc.202