

Expert Opinion on Climate Change and Threats to Biodiversity

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Considerable uncertainty surrounds projections of climate change and its ecological consequences. We surveyed 2329 environmental biologists and found that greater expertise is associated with projections of greater climatic change and more severe consequences. The opinions of scientists with greater expertise converge, and they expect larger temperature increases, higher percentages of species extinctions, and a high percentage of species' ranges will change in response to climate change over the next 100 years. Importantly, even the highest of these estimates is at the lower bounds of many published projections of climate change and threats to biodiversity. These findings suggest that experts are relatively conservative and discerning about the magnitude of climate change and its biodiversity effects, but even their conservative estimates are substantial. We suggest that policymakers consult environmental biologists on emerging and controversial issues such as climate change and use transparent, standardized metrics of expertise when deciding which scientists to consult.

Keywords: climate change, biodiversity, extinction, expert opinion, scientific opinion

The vast majority of peer-reviewed publications on climate change contain predictions of significant temperature increases and negative effects on biodiversity in the coming decades, but these estimates vary considerably depending on the climate model, the time horizon, and the emission scenario used (Bernstein et al. 2007, Anderegg et al. 2010). The scientific estimates also compete with information and misinformation circulated by nonscientific outlets and interest groups (McCright and Dunlap 2010, Oreskes and Conway 2010) and with perceptions of the public and policymakers that scientists exaggerate the amount of climate change and its effects (Slingsby 2001, Reynolds et al. 2010, Weber and Stern 2011). As a result, many nonexperts are uncertain about how much climate change to expect and about its impact on biodiversity. There is some general agreement among the public and policymakers that experts on complex technical issues should be consulted to identify the scope of emerging problems and possible solutions (Bäckstrand 2003). However, little guidance is offered about how to identify such experts and gather their collective understanding about climate change and its ecological effects (Hurtado and Cerezo 2010). This study fills that gap by offering a method of selecting experts and examining their opinions in two important areas of policy relevance: climate change and biotic responses to climate change.

We studied expertise on climate change and on biotic responses to climate change among environmental biologists (ecologists, evolutionary biologists, and conservation biologists) who publish in top peer-reviewed journals.

Environmental biologists are important consumers of climate projections, because they translate climate data into impact assessments (e.g., Root and Schneider 1995). Environmental biologists do not generate climate data themselves but often have deep familiarity with the processes and assumptions underlying those data, as well as their implications (e.g., Fischlin et al. 2007). Within the ecological community, knowledge about climate change and its impacts is therefore relatively sophisticated. However, that knowledge is also variable: Some environmental biologists focus their research, teaching, and applied work on the climate, whereas others focus on subfields less related to the climate. For questions about climate change and biodiversity threats, estimates by the former group should be the most well informed and the most relevant to policy decisions. Using a survey of thousands of published environmental biologists, we show that these experts are, in fact, more knowledgeable about climate changes to date than was the rest of our sample and that their interpretations of future climate change converge. Among the implications of our findings is a recommendation that policymakers consult environmental biologists on emerging and controversial issues such as climate change and use transparent, standardized metrics of expertise when deciding which scientists to consult.

Expert opinion in policymaking

Many common methods of using science in the policymaking process are unsystematic and prone to misrepresenting the range and distribution of scientific evidence

and opinion (Pielke 2007, Keller 2009, Nelson and Vucetich 2009). At times, the misrepresentation emerges from a selective use of science: Some policymakers promote scientific opinion that corresponds with preexisting policy preferences and ignore, downplay, or refute scientific opinion that runs contrary to those preferences (Mooney 2005, Lambright 2008). Policymakers, including those at the highest levels of government (Santorium 2009, Inhofe 2012), often claim that scientific opinion is divided, even in cases such as the anthropogenic causes of climate change, about which scientific disagreement is minimal. At other times, the failure to accurately reflect scientific evidence emerges from policymakers' seeking out scientific opinion without a standardized approach (Lentsch and Weingart 2011). In total, the misunderstanding or misapplication of scientific information can lead government and private-sector entities to inaction or inappropriate action.

Some scholars of science and policy have argued that specific industries and think tanks manipulate or manufacture scientific research to conform to or debunk particular hypotheses (McGarity and Wagner 2008, Michaels 2008, Oreskes and Conway 2010). Such efforts reinforce the perception of division within the scientific community, even when those divisions are minimal. In turn, the perception that the scientific community is divided legitimizes the dismissal of a preponderance of evidence in favor of confirmatory evidence, or what is commonly known as *advocacy science* (McGarity and Wagner 2008, Michaels 2008, Oreskes and Conway 2010). Of course, scientific opinion often is divided (or highly uncertain), and policymakers often seek to understand the divisions and uncertainty. They need methods for understanding the extent and nature of disagreement among knowledgeable scientists.

Currently, members of Congress and other decision-makers often rely on expert witnesses to testify at congressional hearings, to debrief congressional staffers, and to inform the decisionmaking process at the committee level and on the legislative floor. These experts provide information, frame the debate, and help set the agenda (Krehbiel 1992, Lupia and McCubbins 1994). However, there are no broad, generally accepted guidelines for whose testimony should best represent the state of science on a given question. Instead, an unstandardized process prevails in both parties of inviting well-connected or well-known scientists from academia, industry think tanks, and nongovernmental organizations (Rayner 2006, Patt 2007). The process potentially excludes equally or more authoritative scientists whose participation in the political process might be valuable (Pielke 2007, Keller 2009, Nelson and Vucetich 2009).

We suggest that a more systematic approach to including expert opinion in the policymaking process would be useful, using standardized surveys and selecting scientists independent of their policy preferences and on the basis of relatively objective and replicable measures of expertise. Such an approach is especially important for scientific opinion on the effects of modern (human-caused) climate change,

because the scientific literature is in its infancy. In the case of ecological impacts, environmental biologists may be able to share informed insights based on their interpretations of not only the published literature but also on work in progress, dialogue with informed colleagues, and other up-to-the-minute information. We show that scientists with differing degrees of knowledge about climate change predict differing amounts and different biological consequences of climate change, and we argue that the opinions of the most knowledgeable experts may be the most useful in informing policymakers across all branches of government and levels of decisionmaking.

A survey of expert opinion

The goal of our larger project was to learn scientific opinion about biotic responses to climate change and potential adaptation strategies for plants and animals (hereafter, *wildlife*), such as the *managed relocation* of species, defined as the purposeful transporting of species outside their known historic distributions to new regions to counteract the negative effects of climate change (Schwartz et al. 2012). The emphasis in the present article is on the perceived risks of climate change and its impact on biodiversity, a central dimension of the survey. Our survey targeted the world's leading environmental biologists, individuals who are best positioned to understand the distribution and abundance of biodiversity and how it responds to changes in the environment, including climate change. To represent this target population, we aimed to survey scientists who published in the top quartile of ecology, evolution, and conservation biology journals in a recent 5-year period (2003–2008). Using the impact factor rankings of Thomson Reuters's *Journal Citation Reports* for 2008, the year we began the study, we determined that 35 journals fell within the top quartile. Although impact factors are controversial (Monastersky 2005, McLean et al. 2009), they provide a transparent and replicable means of creating a sampling frame, and, importantly for our purposes, the selection process for the best journals should be mostly independent of scientific opinion on climate change and biotic responses and should therefore not bias the selection of scientists. An impact factor measures the average number of citations for a journal over the most recent 2-year calendar period for articles published 3 calendar years earlier (Garfield 2006), which here means that the 2008 impact factor measures the average number of citations in 2006 and 2007 for articles published in 2005.

Our list of published environmental biologists included 15,479 corresponding authors. We chose a census survey approach, sending e-mail invitations to all 15,479, inviting them to participate in a Web-based survey. The corresponding author is the scientist designated to represent that article (e.g., the senior scientist or research director) and should therefore be knowledgeable in the subject matter. By eliminating other authors, we minimized the risk that the sampling frame would include scientists whose contributions may have been minimal.

To maximize the number of responses and to minimize bias, we employed incentives and reminders, and we systematically attempted to convert refusers. Given the scientists' income brackets and busy schedules, we chose not to offer a monetary incentive. Instead, we informed them of the exclusiveness of the target population and the importance of their particular opinions as members of this target population. ("We are contacting only scholars such as you who have published in the top quartile of environmental journals in the last several years. We would be grateful for your participation.") We also offered a professional incentive in the form of data. ("At the end of the survey, there will be an opportunity for you to provide your e-mail address so that you can receive information about the results of this survey.") The respondents received e-mail invitations to complete a Web-based survey and then six reminders over the course of 8 weeks. The invitations were sent in batches between 19 October 2010 and 6 May 2011. The respondents who e-mailed to decline participation (220) all received a personalized reply attempting to convert the refusal by acknowledging the legitimacy of their concerns and emphasizing the value of their expertise. Many initial refusers claimed that they were persuaded to participate, although confidentiality procedures prevent us from knowing whether they actually did participate.

The survey was approved for the use of human subjects by the University of Notre Dame's Institutional Review Board. The respondents received and acknowledged a statement of informed consent prior to beginning the survey that included information about confidentiality, the voluntary nature of survey participation, and the absence of risk associated with participation.

The response rate was 15%, or 2329 respondents of the targeted 15,479, a rate not ideal but consistent with past studies and evidence of the challenges associated with declining response rates for Web surveys (Kaplowitz et al. 2004, Doran and Zimmerman 2009). The survey took an average of 51 minutes to complete. To our knowledge, no previous study of expert opinion about climate change or its impacts has included such a large sample size from across a broad range of institutions and expertise.

No independent data are available to assess the impact of nonresponse on our results, but our correspondence with 220 nonrespondents suggests that, compared with the target population, our achieved sample includes a higher proportion of scientists who accept or are at least not skeptical of the relevance of their publication record to climate change and adaptation strategies for wildlife. The vast majority of our corresponding nonrespondents (170 of 220) offered as the reason for nonparticipation their perception that their expertise is unrelated to wildlife adaptation. We believe that it is reasonable to assume that this perception is shared by many of the nonrespondents who did not communicate with us. (Recall that the target sample is defined as having potentially relevant opinions because they publish in directly relevant fields.) If the assumption is correct that

nonresponse is driven primarily by a perception of unrelated expertise and if the nonrespondents have even less knowledge about climate change and biotic effects than do our least knowledgeable respondents, the results reported below are probably conservative, although we, of course, cannot be certain. In particular, the differences between environmental biologists with expertise highly relevant to climate change and environmental biologists with less relevant expertise may be greater than we report.

All of the respondents, by virtue of landing in our sampling frame, possess some kind of scientific expertise. Professors at research universities or teaching colleges represented 58% of the respondents, and the remaining were mostly postdoctoral researchers (19%), research personnel at government or nongovernment agencies (17%), or students (2%). Almost all had PhDs (95%). However, some respondents had relatively greater knowledge than did others about climate change and its effects on biota. To measure climate-related expertise within our expert pool, we used survey questions that asked for self-ratings of knowledge from *poor* to *excellent* on three different areas of research: "Compared to other people who publish in the top quartile of environmental science journals, how would you rate your level of knowledge about climate change, biotic responses to climate change, and invasive species?" We also asked how many of the respondents' publications to date (single or multiple author) addressed each of these three research areas. The questions about invasive species allowed us to test whether expertise in a nonclimate field influences opinions on climate change and biotic responses or whether opinion is influenced only by climate-related expertise. Table 1 shows the descriptive statistics for all of the survey questions reported in this article.

Measuring climate-related expertise

There was a strong, positive correlation between the self-assessed level of knowledge and the number of publications on climate change ($r = .46, p < .001$), biotic responses to climate change ($r = .53, p < .001$), and invasive species ($r = .59, p < .001$). As table 2 shows, the respondents who offered higher self-assessments of their knowledge in each of these research areas had more publications on average in those areas. The respondents who assessed their knowledge of any research area as *poor* had very few publications in that area (means of 0.14, 0.34, and 0.19 publications for climate change, biotic responses, and invasive species, respectively). The respondents who assessed their knowledge of climate change as *excellent* had an impressive mean of 17 publications on climate change, the respondents with *excellent* self-assessed knowledge of biotic responses to climate change had a mean of 15 publications in that area, and those who self-assessed their knowledge of invasive species as *excellent* had 17 publications. The standard errors were low (fewer than 3 publications; see table 2).

As a check on the scientists' self-reporting, we also asked a factual question about observed climate change: "What is

Table 1. Survey response statistics.

Question	Respondent type														
	Full sample (N = 2329)			Excellent self-reported knowledge of climate change (n = 75)			Excellent self-reported knowledge of biotic responses to climate change (n = 127)			10 or more publications on climate change (n = 137)			10 or more publications on biotic responses to climate change (n = 260)		
	Mean	Standard deviation (SD)	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD
"In your opinion, within the next 100 years, how likely is it that the earth's average temperature will increase?" ^a	3.81	0.44	0.49	3.81	0.49	0.24	3.94	0.24	0.51	3.78	0.51	0.51	3.78	0.51	0.51
"If you think that the earth is warming, what is your overall best guess for the number of degrees Celsius that the earth's average temperature will increase in 100 years, and what is your best guess for the likely minimum number of degrees and likely maximum number of degrees?"	3.03	1.41	1.47	3.49	1.47	1.26	3.31	1.26	1.52	3.29	1.52	1.27	3.17	1.27	1.27
Likely minimum increase	1.51	0.94	1.14	1.90	1.14	1.01	1.79	1.01	1.02	1.69	1.02	0.93	1.68	0.93	0.93
Likely maximum increase	5.13	2.29	2.20	5.70	2.20	2.07	5.54	2.07	2.26	5.43	2.26	1.96	5.25	1.96	1.96
"What is your best guess of the recorded change in the earth's average temperature during the last 100 years? Decimals allowed."	1.34	1.14	0.83	1.11	0.83	0.77	1.13	0.77	0.77	1.13	0.77	0.71	1.10	0.71	0.71
"In your opinion, what percentage of non-microbial species will be committed to extinction solely due to climate change in the absence of other causes within the next 100 years?"	9.5	9.3	10.68	12.43	10.68	10.49	11.61	10.49	11.34	12.12	11.34	9.30	10.94	9.30	9.30
"In your opinion, what percentage of non-microbial species will be committed to extinction due to a combined effect of climate change and other causes within the next 100 years?"	21	15.6	14.63	22.81	14.63	15.45	23.28	15.45	17.12	23.91	17.12	15.06	23.51	15.06	15.06
"For those non-microbial species that do not go extinct under climate change, what percentage of them do you think will have altered geographic ranges caused by climate change in 100 years?"	51.8	28.0	31.23	58.96	31.23	28.22	61.77	28.22	29.43	57.15	29.43	28.15	58.39	28.15	28.15

Note: ^aOn a four-point scale: 1, not at all likely; 2, not very likely; 3, rather likely; 4, very likely.

Table 2. Mean number of publications on a specific topic for each level of self-assessed knowledge.

“Compared to other people who publish in the top quartile of environmental science journals, how would you rate your level of knowledge about [climate change, biotic responses to climate change, invasive species]?”	Topic					
	Climate change		Biotic responses to climate change		Invasive species	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Poor	0.14	0.51	0.34	1.06	0.19	0.65
Fair	0.75	2.89	1.27	3.72	1.01	2.98
Good	2.47	7.96	3.65	9.48	2.7	5.08
Very good	5.1	10.78	8.01	13.77	9.72	15.53
Excellent	17.3	24.76	15.25	19.28	17.28	22.11

your best guess of the recorded change in the earth’s average temperature during the last 100 years?” An accurate answer was the value published in the 4th Assessment Report of the IPCC of 0.74 degrees Celsius (°C; Bernstein et al. 2007). Approximately 16% of the respondents answered either 0.7°C or 0.8°C; another 16% answered either 0.5°C or 0.6°C, and the modal responses were 1°C (25% of the respondents) and 2°C (15% of the respondents). Only 9% of the respondents answered with a number higher than 2°C.

Importantly, the experts on climate change, their expertise having been confirmed by a higher number of publications and higher self-assessed level of knowledge, came significantly closer on average to the International Panel on Climate Change (IPCC) estimate (Bernstein et al. 2007) than did the scientists with other levels of expertise. The respondents who had published 10 or more articles on climate change or who assessed their knowledge of climate change as *excellent* had a mean response of 1.1°C, whereas the respondents with no publications on climate change or a self-assessment of *poor* knowledge had a mean response of 1.4°C and 1.5°C, respectively, differences of 18% and 36%, respectively.

This pattern also holds true for the variation in expertise on biotic responses to climate change: The more publications on biotic responses to climate change and the higher the self-assessed level of knowledge were, the closer were the scientists’ responses on the recorded average temperature change over the last 100 years to the IPCC estimate, with means of 1.1°C for the respondents who published 10 or more articles on biotic responses to climate change or had *excellent* self-assessed knowledge compared with means of 1.4°C for those with no publications or *poor* self-assessed knowledge. Importantly, variation in expertise on invasive species did not reveal a statistically significant relationship with the IPCC estimate of recorded temperature change. A higher number of publications and a higher self-assessed level of knowledge of invasive species were unrelated to knowledge of past climate change.

Scientists with climate-related expertise predict greater climate change

We asked the respondents how likely it was that the Earth’s average temperature would increase over the next 100 years,

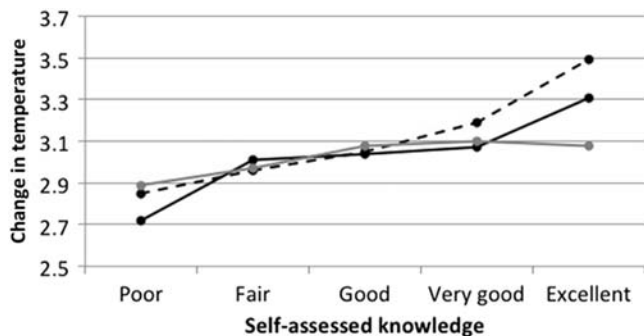


Figure 1. Expertise and mean temperature change estimates (in degrees Celsius): “Compared to other people who publish in the top quartile of environmental science journals, how would you rate your level of knowledge about climate change [the dashed line], biotic responses to climate change [the black line], and invasive species [the gray line]?” and “If you think that the earth is warming, what is your overall best guess for the number of degrees Celsius that the earth’s average temperature will increase in 100 years?” (N = 2329).

and for those who answered *rather likely* or *very likely* (98.4% of the respondents; compare this to the 1.6% who responded that it was *not very likely* and the single respondent who said that it was *not at all likely*), we asked for their best overall estimate of the temperature increase, as well as a likely minimum and maximum change. We then compared the responses of scientists with different levels of climate-related expertise, indicated by their self-assessed level of knowledge and their number of publications.

Figure 1 shows the mean predicted overall estimate for the potential temperature increase for respondents with different self-assessed levels of knowledge of climate change, biotic responses to climate change, and invasive species. The higher the self-assessed level of knowledge of climate change and biotic responses to climate change was, the higher the respondent’s estimated future temperature increase (the difference between the estimates of the respondents with *poor* and those with *excellent* self-assessed knowledge of climate

change was 0.643°C [$p < .001$]; that for biotic response was 0.592°C [$p < .006$].

The pattern of response for climate change and biodiversity expertise was not replicated for invasive species expertise. There was no statistically significant correlation between the respondents' self-assessed level of knowledge of invasive species and the overall estimate for temperature increase over the next 100 years, which means that we get no different insight into estimated climate change from a scientist with *poor* knowledge of invasive species than from one with *excellent* knowledge (the difference between estimates was 0.182°C [$p < .181$]). Figure 1 also illustrates the patterns for the predicted likely minimum temperature increase and the predicted likely maximum increase, which both increase with the self-assessed level of knowledge. The pattern remains the same if we substitute the number of publications for the self-assessed level of knowledge.

Climate experts (i.e., those with a high self-assessed level of knowledge and high number of publications) estimated, on average, that temperature will increase between 3.3°C and 3.5°C over the next 100 years. These estimates are conservative relative to the range of "likely" projected temperature change by the end of the century, according to the IPCC summary for policymakers (2.4°C – 6.4°C ; Bernstein et al. 2007). Most of our respondents provided answers within the range of IPCC projection boundaries, and the estimates of the climate experts are higher, but few approach the high end of the IPCC's "likely" range.

Scientists with climate-related expertise predict greater biotic impacts of climate change

We asked the respondents what percentage of currently extant nonmicrobial species would be rendered extinct with climate change as the sole cause over the next 100 years, and we again compared the responses of scientists with different levels of relevant expertise, which was indicated by their self-assessed level of knowledge and their number of publications.

Figure 2 shows the mean percentage of species committed to extinction estimated by respondents with different self-assessed levels of knowledge of climate change, biotic responses to climate change, and invasive species. The higher the self-assessed level of knowledge of climate change and biotic responses to climate change was, the higher the estimates of extinctions were.

Again, the correlations were statistically significant and approximately linear ($r = .13$ for climate change knowledge and $r = .10$ for biotic response [both $ps < .001$]), with higher estimated extinctions for each higher level of self-assessed knowledge. The respondents with *poor* self-assessed knowledge of climate change or biotic responses to climate change estimated a mean of 7% of species committed to extinction, and the respondents with *excellent* self-assessed knowledge estimated a mean of 12%. As with the predicted amount of climate change, these estimates are aligned with but on the lower end of published predictions (e.g., 15%–40% in

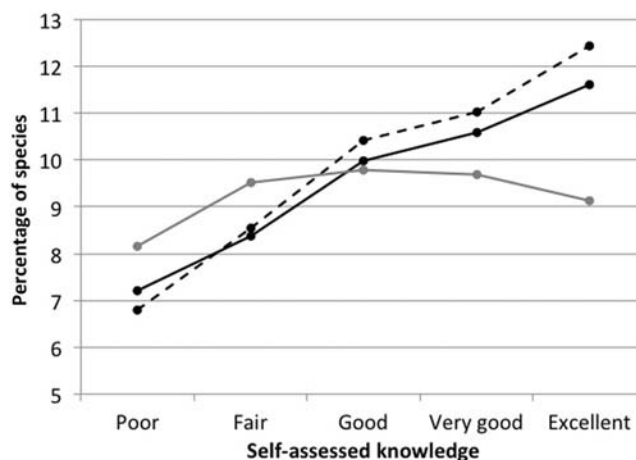


Figure 2. Expertise and mean species extinction estimates: “Compared to other people who publish in the top quartile of environmental science journals, how would you rate your level of knowledge about climate change [the dashed line], biotic responses to climate change [the black line], and invasive species [the gray line]?” and “In your opinion, what percentage of non-microbial species will be committed to extinction solely due to climate change in the absence of other causes within the next 100 years?” (N = 2329).

Thomas et al. 2004; see also Botkin et al. 2007, Maclean and Wilson 2012). Again, expertise on invasive species was not significantly predictive of the distribution of responses ($r = .02$, $p = .153$).

These patterns held for the other survey questions. There was wide agreement that a large percentage of species will go extinct in response to the combined effects of climate change and other causes over the next 100 years, but those respondents with *poor* self-assessed knowledge of climate change or biotic responses to climate change estimated a mean of 17% and 16%, respectively, whereas those with *excellent* self-assessed knowledge estimated a mean of 23%. There was also wide agreement among the respondents that a large percentage of species would alter their geographic ranges because of climate change over the next 100 years, but those with *poor* self-assessed knowledge of climate change or biotic responses to climate change estimated a mean of 46% or 44%, respectively, whereas those with *excellent* self-assessed knowledge of climate change or biotic responses estimated a mean of 59% or 62% of species, respectively. These differences were significant at an alpha level of .001, whereas the differences based on expertise on invasive species were not statistically significant.

Conclusions

Our survey of 2329 environmental biologists is, to our knowledge, the largest systematic survey of expert opinion about climate change and its impacts. We measured the expertise of our respondents as their self-assessed level of knowledge and their number of publications about climate

change and the biotic impacts of climate change, and these measures were validated against answers to a relatively verifiable question about the Earth's average temperature over the last 100 years. The level of expertise on climate change and biotic responses to climate change varied significantly with the responses to the verifiable question, whereas expertise on invasive species did not. Given that most experts on invasive species would have less reason to study past climate change than would experts on climate and biodiversity, these relationships make sense and validate measuring expertise with self-assessments and the number of publications in specific subfields.

Among the published environmental biologists, those with greater climate-related expertise more accurately reported observed amounts of climate change. These individuals also predicted larger increases in future climate change and larger impacts of climate change, including higher predictions of species extinctions and range shifts. In comparison, there was no relationship between greater knowledge of invasive species and observed or predicted climatic change or predicted species extinctions, again suggesting that our survey correctly identified experts on climate change issues.

The respondents at all levels of expertise offered fairly conservative estimates of future climate change, with even the most knowledgeable and highly published individuals reporting values below the midpoint of expected warming projected by the IPCC (3.7°C and 4.4°C for its A2 and A1FI scenarios, respectively; Bernstein et al. 2007). Similarly, the biological risks of climate change to species estimated by our respondents were also low relative to published values, although most of the respondents agreed that extinctions would occur. These results challenge the notion among some policymakers and the public that scientists overestimate the magnitude and effects of global warming (Slingsby 2001, Weber and Stern 2011). Still, the lower values revealed in this survey represent an alarmingly large change.

These findings have other important implications for policymakers. In the decisionmaking process, experts whose fields are most relevant to the decision at hand may offer more informed opinions than would experts on less-related fields. Not differentiating among scientists by their specializations risks misstating the most up-to-date thinking by the foremost specialists. For example, the scientists in this study with climate-related expertise had the greatest concern about climate change and its effects on biota, and these concerns would be significantly understated if they were bundled together with the lesser concerns of scientists with other expertise, such as expertise on invasive species.

Finally, this study demonstrates the importance of amassing a survey population in a relatively objective and transparent way to differentiate scientists on the basis of their expertise. Our findings also suggest that the self-assessed level of knowledge and the number of relevant publications could be useful measures of expertise in specific subfields, especially when we are able to validate the self-assessments and self-reporting with external information, such as with

published observations. We suggest that policymakers use specific metrics of expertise, such as self-assessed knowledge and the number of relevant publications when deciding which scientists to consult on emerging and controversial issues, such as climate change. Such an approach would allow for a standardized, replicable, and relatively objective representation of scientific opinion in the policymaking process.

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