Ocean Research Priorities: Similarities and Differences among Scientists, Policymakers, and Fishermen in the United States

JULIA G. MASON, MURRAY A. RUDD, AND LARRY B. CROWDER

Understanding and solving complex ocean conservation problems requires cooperation not just among scientific disciplines but also across sectors. A recently published survey that probed research priorities of marine scientists, when provided to ocean stakeholders, revealed some agreement on priorities but also illuminated key differences. Ocean acidification, cumulative impacts, bycatch effects, and restoration effectiveness were in the top 10 priorities for scientists and stakeholder groups. Significant priority differences were that scientists favored research questions about ocean acidification and marine protected areas; policymakers prioritized questions about habitat restoration, bycatch, and precaution; and fisheries sector resource users called for the inclusion of local ecological knowledge in policymaking. These results quantitatively demonstrate how different stakeholder groups approach ocean issues and highlight the need to incorporate other types of knowledge in the codesign of solutions-oriented research, which may facilitate cross-sectoral collaboration.

Keywords: research priorities, transdisciplinary, oceans research, knowledge coproduction

Complex conservation problems often call for interdisciplinary solutions. For decades, scientists have recognized the importance of interdisciplinary collaboration in conservation research (Daily and Ehrlich 1999, Mascia et al. 2003, Balmford and Cowling 2006) and, more recently, the need to engage and communicate with stakeholders outside academia (Sutherland et al. 2012, Ban et al. 2013, Cvitanovic et al. 2014). There has been a recent upsurge in interest in interdisciplinary and even transdisciplinary environmental science (e.g., Mooney et al. 2013, Pahl-Wostl et al. 2013, Pennington et al. 2013, Weaver et al. 2014), with increased focus on the coproduction of knowledge by cross-cutting teams that span disciplines, draw on large and diverse data sets, and involve scientists, policymakers, and stakeholders in the research process (e.g., Hampton and Parker 2011, Armitage et al. 2015, Palmer et al. 2016). Knowledge produced in this way may be more closely aligned with societal needs, help forge new science–policy networks, have more concrete policy impact, and help society identify and implement effective and efficient interventions that address environmental challenges (Rudd 2011, Sutherland et al. 2011).

Such was the rationale for recent prioritization exercises to identify important research questions that, if answered, would help guide policy-aligned research for the most pressing challenges relating to the conservation of biodiversity (e.g., Sutherland et al. 2009, Fleishman et al. 2011, Rudd 2011, Sutherland et al. 2013, Varma et al. 2015) or, increasingly, other subfields in the environmental sciences (e.g., Parker et al. 2014, Kennicutt et al. 2015, Oldekop et al. 2016). Those exercises, conducted in a bottom-up manner that engaged scientists and/or policymakers, were systematically structured (Sutherland et al. 2011) to encourage consideration of diverse issues through the widespread solicitation of candidate issues and iterative discussions of these issues in workshops with scientists and/or policymakers. More recently, the important questions identified in priority exercises have been explicitly ranked in follow-up surveys and syntheses (Rudd and Lawton 2013, Rudd 2014, Rudd et al. 2014, Rudd and Fleishman 2014), two of which focused exclusively on coastal and ocean sustainability challenges (Rudd and Lawton 2013, Rudd 2014). These surveys focused on scientists and revealed complex patterns of research prioritization across disciplines and regions. But unlike the US conservation science follow-up that explicitly compared research priorities for scientists and managers (Rudd and Fleishman 2014), the coastal and ocean research questions

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have not yet been prioritized by managers and policymakers, much less resource users such as fishermen.

In this study, we used an abbreviated list of 25 important research questions from Rudd's (2014) synthesis in a survey delivered to US ocean stakeholders, including managers, policymakers, and—for the first time in these quantitative, exercise-based prioritization studies—ocean resource users. We sought to compare the priorities of this target audience with those of the US scientists surveyed in Rudd's (2014) global survey to gain insight into how different ocean stakeholder groups approach and evaluate ocean issues. By directly comparing priorities for the same questions in each survey, we quantitatively identified which questions emerged as important to different groups and what topics were more prone to agreement or disagreement. Examining how different groups value and prioritize ocean issues should help foster a greater understanding of how transdisciplinary, collaborative research could be designed and implemented (Klein 2004, Mauser et al. 2013), as well as facilitate more effective science advice in the future (Rudd and Lawton 2013, Spruijt et al. 2014).

Question selection

In order to ensure comparability with Rudd's (2014) survey, we used the questions from that survey with wording intact. For brevity, we reduced the number of questions from 67 to 20 by using a latent class cluster analysis (LCA) on Rudd's (2014) results ($n = 2187$ respondents) to identify individual questions with the most potential for the differentiation of research priorities among different categories of survey respondents. To combat possible disconnect between clusters for scientists and those for stakeholders, an additional 5 questions (selected in consultation with policy experts at Stanford's Center for Ocean Solutions and California's Ocean Science Trust) from the original 67 were added to the survey to increase the breadth of the questions and their relevance to US marine and coastal issues. All questions used in the survey are listed in table 1, with directly selected questions indicated with an asterisk.

Survey instrument

The survey instrument was adapted from Rudd (2014) and built with Sawtooth Software (Version 8.3.10, January 2015). The respondents ranked the questions using best–worst scaling (BWS): They were presented with four of the questions at a time and selected the relative *most important* and *least important* of the four. As in Rudd (2014), the respondents were presented with each question at least twice, and each respondent was presented with a total of 14 BWS tasks in a randomly assigned order from one of 300 versions. After finishing the rankings, the respondents were presented with a list of their calculated top five and bottom five priorities and given the opportunity to report how well this list reflected their true priorities (*excellent*, *good*, *fair*, *poor*). The survey respondents also provided demographic information, including US state of residence, age, gender, highest level of education, and years of experience working with marine-related issues. They were invited to choose the sector that best described their employment: federal government, state government, local government, nonprofit or nongovernmental organization (NGO), private business, commercial fishery, seafood industry, or other (specified), as well as to provide their job title. Much of the survey format and wording were directly modeled after Rudd (2014); where possible, content was trimmed or moved to external links to minimize time burden (see supplemental appendix S1 for an example of the survey and prioritization exercises). The survey was approved by Stanford's Institutional Review Board on 2 April 2015 and was open from 9 April 2015 to 21 May 2015.

Sample

The target sample for the survey was marine and coastal policymakers, managers, and resource users employed in the fisheries sector (e.g., commercial fishers but not recreational fishers) residing in the United States. We hereafter collectively refer to this group as *stakeholders* to distinguish them from the scientists in Rudd's (2014) original survey, although we recognize that marine scientists, too, are stakeholders in ocean conservation. Because this survey was the first to use this prioritization method with ocean resource users, we limited our focus to individuals in the wild-caught seafood sector—commercial fishermen and seafood processors—for simplicity. Ocean resource users are less straightforward to identify and contact than scientists and government officials, and our hope was that concentrating efforts on one group would increase our likelihood of reaching a larger sample size. Fishermen and the fisheries sector were selected because they are a prominent group with livelihoods dependent on the oceans, and fishing is routinely identified as a major threat to ocean health, with a more easily identifiable associated stakeholder group than issues such as climate change or ocean acidification (Jackson et al. 2001, Halpern et al. 2008). We also limited the sample to professionals in the interest of clearly delineating stakeholders as those whose livelihoods and employment are directly related to ocean issues, much as Rudd (2014) sampled professional but not citizen scientists. This was also a measure to avoid overlap in roles: A scientist or policymaker may also be a recreational fisherman but is unlikely to also be a commercial fisherman.

We directly emailed 1582 individuals identified from publicly available government agency, NGO, fishery management commission, and fishermen's and seafood processors' association websites, targeting individuals with job titles or in departments that suggested involvement in marine or coastal issues. We also asked the respondents to forward the survey link to appropriate colleagues, collaborators, and associates. We focused on federal and state government agencies, NGOs and businesses engaged in marine and coastal management, commercial fishermen, and seafood processors but did not explicitly exclude local government officials or other professional ocean stakeholders in hopes

Table 1. The questions used in this survey (in the order of the scientists' rankings in Rudd 2014). The asterisks denote the five questions selected for relevance to US coastal and marine stakeholders rather than through latent class cluster analysis.

	Abbreviation	Full Question Text	Overall rank by scientists, Rudd (2014)
Q1	Ocean acidification*	How will ocean acidification affect marine biological diversity, including noncalcifying organisms, and ecosystem function and processes such as nutrient speciation and availability, trophic interactions, reproduction, metabolism, and diseases?	3
Q2	Monitoring cumulative effects	What monitoring technologies and methods can effectively and efficiently deliver comparable ocean data and data products for observation and assessment in the long-term, incremental, and cumulative effects of multiple stressors in the marine environment?	4
Q3	Coral-reef management strategies	Which management actions are most effective for ensuring the long-term survival of coral reefs in response to the combined impacts of climate change and other existing stressors?	18
Q4	Ocean literacy messages	What are the most critical messages and concepts that should be communicated to citizens to change their beliefs and attitudes regarding ocean health and management, and will those messages change behavior?	21
Q5	Aquaculture effects*	How can aquaculture and open-water farming be developed so that impacts on wild fish stocks and coastal and marine habitats are minimized?	23
Q6	Upland hydrology effects on oceans	How will changing terrestrial hydrological regimes affect coastal and marine ecosystem structure, function, and services?	24
Q7	Bycatch effects*	How can the impacts of bycatch from legal and illegal, unreported, and unregulated fisheries be reduced to a level that will allow for the reversal of declining trends of affected species?	25
Q8	Sea-level rise and vulnerable coasts	How can the relationships between coastal sea-level forcing mechanisms, regional variability in sea-level rise, and future storm tracks be modeled and used to identify and protect vulnerable coastlines?	26
Q9	Restoration effectiveness	To what extent can coastal and ocean habitat restoration or rehabilitation compensate for loss of the quantity or quality of existing species' habitat?	29
Q10	MPAs and resilience*	To what degree can no-take or highly protected MPAs provide resilience or a buffer against ecosystem disruption caused by climate change and ocean acidification?	30
Q11	Risk assessment for governance*	How should uncertainty, risk, and precaution be incorporated into effective ocean governance and policymaking?	34
Q12	Coastal hazard management	How can the spatial extent, frequency, and risk of marine hazards affecting coastal waters (e.g., hydrate-triggered landslides, tsunamis, and extreme storm events) be forecast and their effects minimized?	35
Q13	Uncertainty in modeling	How can we efficiently and effectively plan adaptation measures to cope with extreme events given the uncertainty associated with model predictions?	42
Q14	Polar oil spills	What are the impacts of oil spills in cold and deep oceans and under sea ice, and what are the appropriate strategies and technologies for prevention and mitigation?	44
Q15	High seas governance	What are the unique challenges of high-seas management, and what are the best methods for ensuring effective and credible high-seas governance and conservation outside the legal jurisdiction of any single country?	46
Q16	Shifting ecological baselines	How can effective policymaking and evaluation of marine systems be proactively advanced in light of the recognized shifting of historical baselines?	52
Q17	Ecosystem service valuation implications	How can marine goods and services be valued, and how will the adoption of monetary value by ocean managers affect the conservation of marine resources?	53
Q18	Local ecological knowledge	How can local and traditional knowledge be most effectively communicated and synthesized with scientific knowledge to inform ocean science management and governance?	54
Q19	Effects of marine diseases on human health	How can we best manage diseases that have the potential to move among wild and domestic marine species and directly or indirectly affect human health?	55
Q20	Management capacity of human communities	What are the effects of different strategies for building community capacity on the levels of citizen engagement in coastal and ocean stewardship, restoration, and conservation?	56
Q21	Information for sustainable food choices	What information is most useful to consumers wishing to make informed decisions about the environmental and social impacts of their seafood choices?	62
Q22	Macroalgal culture	What are the economic opportunities for and ecological consequences of rapidly increasing macroalgal culture as a raw material for food and biofuel production?	63
Q23	Human dissociation from nature	What are the effects of increasing human dissociation from nature on the conservation of marine biological diversity?	64
Q24	Effects of worldviews on conservation	How have humankind's various worldviews shaped the perceptions, relationships, and narratives related to the marine environment, and how do these influence marine conservation?	65
Q25	Job creation	What types and numbers of jobs can be created by ocean research?	67

of broadening the sample. For those we directly emailed, we sent up to two reminders and a final notice to those who had not completed the survey. In order to reach a higher number of respondents, we also publicized the survey via California's Ocean Science Trust and Stanford's Center for Ocean Solutions Twitter accounts, a blog post on *www.oceanspaces.org*, the *Ocean Spaces* newsletter, and *Pacific Fishing Magazine*'s website and daily "FishWrap" news digest email. Although we recognize the risk of bias in these nonprobability sampling techniques, our primary objective was to compare priorities among different groups, so our sampling strategy was deemed most appropriate in the interest of reaching as many respondents as possible in groups for which there were no means of formally constructing a sample frame. The subset of US respondents from Rudd's (2014) survey of scientists ($n = 549$) was used for comparison.

Data analysis

Sawtooth Software uses hierarchical Bayesian (HB) analysis to assign scaled ranking scores to each respondent, which represent the probability of the respondent ranking that particular question as most important. We used Sawtooth's default settings for this calculation (prior variance = 2; degrees of freedom = 5; 20,000 iterations for burn-in; 10,000 iterations for coefficient calculation). Median scaled scores were used to order ranks of questions, after Rudd (2014).

We compiled ordered median ranks of questions for the overall sample and across demographic and professional groups for all the nonscientist respondents who fully completed the survey ($n = 351$). Rudd's (2014) results for scientists were rescaled using only the 25 questions tested in this survey, and the subset of US respondents was used for comparison ($n = 549$), so comparisons and analyses were performed on a total sample of 900 respondents. Homogeneity of variances was calculated using Levene's test (Schultz 1985), and differences in median ranks of each question within the sample and with Rudd's results were compared using pairwise nonparametric Wilcox tests with a Bonferroni correction.

Unpaired Wilcox tests were used to determine statistical differences among self-reported groups of stakeholders, and used to divide the sample into groups. Tests were performed on every question across self-reported sector (e.g., "federal government" or "seafood industry"), and sectors were grouped together if they were statistically indistinguishable at the 95% level with a Bonferroni correction.

Principal components analysis (PCA) was used to examine patterns in responses among scientists and stakeholder groups. All US scientists were compared to statistically determined groups of stakeholders to evaluate how groups aligned along key questions, defined as those appearing in the top five priorities of scientists and each stakeholder group. Scientists were also divided into discipline, as was self-reported in Rudd's (2014) survey, to examine how the natural ($n = 339$), physical ($n = 163$), and social ($n = 47$) scientists aligned with stakeholder groups.

The survey participants

A total of 417 respondents from 30 states and territories completed the survey, and another 846 viewed or partially completed the survey. Because of the open survey, we were unable to record a response rate. Three respondents who indicated that they were not residents of the United States were removed from the sample. Any participant who self-identified as a research scientist was asked to opt out of the survey; however, 63 of the respondents that completed the survey included the word *scientist*, *ecologist*, or *biologist* in their self-reported primary job titles. Government scientists or scientifically trained policy advisors inhabit a gray area on the science–policy spectrum, so we used these self-identifiers to determine whether the respondents considered themselves more scientists or stakeholders. In the interest of making a clearer distinction between scientists and stakeholders, we omitted these self-reported scientists from the sample for statistical analysis, with a resulting sample of $n = 351$.

The survey took the participants a median of 21 minutes (a range of 6 minutes to nearly 5 hours, with 25% and 75% quantiles at 15 minutes and 34 minutes, respectively). Self-reported measures of how well the calculated list of priorities fit the respondents' true priorities were 88 (25%) *excellent*, 207 (59%) *good*, 55 (16%) *adequate*, and 1 (0%) *poor*. The majority of respondents were male, from the west coast, employed in state government, and with a master's degree. Industrial and resource-user interests constituted 16% of the sample, and no respondent indicated a job title or *other* sector that classified them as a resource user outside of the fisheries and seafood sector. The respondents' demographics are summarized in the supplemental appendix S2.

Priorities

The top two (ocean acidification, Q1; monitoring cumulative effects, Q2) and bottom five (information for sustainable food choices, Q21; macroalgal culture, Q22; human dissociation from nature, Q23; effects of worldviews on conservation, Q24; and job creation, Q25) priorities were similar between US scientists and stakeholders. In general, stakeholders prioritized local ecological knowledge (Q18) and risk assessment for governance (Q11) higher than did scientists and marine protected areas (MPAs) and resilience (Q10), coastal hazard management (Q12), and coral-reef management (Q3) lower, as was evidenced by differences of more than five places in overall rankings (table 2). Ocean acidification (Q1), monitoring cumulative effects (Q2), bycatch effects (Q7), and restoration effectiveness (Q9) appeared in the top 10 priorities for all self-reported stakeholder sectors and scientists (table 3).

In the top-ranked 10 questions among stakeholder sectors, risk assessment for governance (Q11) appeared in all groups. Ocean literacy messages (Q4) appeared in all groups except the seafood industry. Local ecological knowledge (Q18) emerged as the top priority for the seafood industry and commercial fishermen and sixth and seventh for NGOs and

Table 2. Question rankings. The scientists' rankings are from Rudd (2014), and the stakeholders' rankings are from all stakeholder respondents in this study.

Rank	Scientists' Rankings (n = 549)	Stakeholders' Rankings (n = 351)
1	Ocean acidification (Q1)	Monitoring cumulative effects (Q2)
2	Monitoring cumulative effects (Q2)	Ocean acidification (Q1)
3	Coral-reef management strategies (Q3)	Bycatch effects (Q7)
4	Ocean literacy messages (Q4)	Restoration effectiveness (Q9)
5	Sea-level rise and vulnerable coasts (Q8)	Risk assessment for governance (Q11)
6	Upland hydrology effects on oceans (Q6)	Ocean literacy messages (Q4)
7	Bycatch effects (Q7)	Sea-level rise and vulnerable coasts (Q8)
8	Restoration effectiveness (Q9)	Upland hydrology effects on oceans (Q6)
9	MPAs and resilience (Q10)	Coral-reef management strategies (Q3)
10	Aquaculture effects (Q5)	Local ecological knowledge (Q18)
11	Uncertainty in modeling (Q13)	Shifting ecological baselines (Q16)
12	Coastal hazard management (Q12)	Uncertainty in modeling (Q13)
13	Risk assessment for governance (Q11)	Aquaculture effects (Q5)
14	Polar oil spills (Q14)	High-seas governance (Q15)
15	Shifting ecological baselines (Q16)	Polar oil spills (Q14)
16	High-seas governance (Q15)	MPAs and resilience (Q10)
17	Effects of marine diseases on human health (Q19)	Ecosystem service valuation implications (Q17)
18	Ecosystem-service-valuation implications (Q17)	Management capacity of human communities (Q20)
19	Management capacity of human communities (Q20)	Coastal hazard management (Q12)
20	Local ecological knowledge (Q18)	Effects of marine diseases on human health (Q19)
21	Information for sustainable food choices (Q21)	Information for sustainable food choices (Q21)
22	Macroalgal culture (Q22)	Human dissociation from nature (Q23)
23	Human dissociation from nature (Q23)	Effects of worldviews on conservation (Q24)
24	Effects of worldviews on conservation (Q24)	Macroalgal culture (Q22)
25	Job creation (Q25)	Job creation (Q25)

private businesses, respectively. Federal and state (including local) government and NGOs prioritized coral-reef management strategies (Q3), sea-level rise and vulnerable coasts (Q8), and upland hydrology effects on oceans (Q6), whereas private business, seafood industry, and commercial fishermen prioritized high-seas governance (Q15). Seafood industry and commercial fishermen included aquaculture effects (Q5), and fishermen and private business included information for sustainable food choices (Q21). Shifting ecological baselines (Q16) uniquely appeared in federal government top priorities, uncertainty in modeling (Q13) in state or local government, management capacity of human communities (Q20) in private business, and ecosystem valuation implications (Q17) and polar oil spills (Q14) in seafood industry top priorities (table 3).

Stakeholder groups

Statistical analysis of differences among self-identified stakeholder groups in the prioritization of each question ultimately revealed two groups: policymakers and resource users. We use the terms *policymakers* ($n = 300$) to concisely, if not entirely accurately, refer to the respondents who selected federal government, state and local government, NGOs or nonprofits, and private business as their primary sector of employment, and we use *resource users* ($n = 51$) to refer to the respondents who selected the seafood industry and commercial fishing. Although the federal government and state or local government respondents did significantly differ in their ranking of the question on ocean acidification (adjusted $p = .029$), neither group significantly differed from the rest of the policymakers for that question, so they are grouped together for simplicity. Private business ($n = 14$) did not significantly differ from any other self-reported stakeholder group for any question, but they are grouped with policymakers for simplicity because they were more statistically similar to NGOs than to the seafood industry or fishermen.

Each broad stakeholder group as well as each self-reported stakeholder sector significantly differed from the scientists for at least three questions. The policymakers significantly differed from the scientists for 15 questions, and the resource users significantly differed from the scientists for 20 questions. The scientists ranked ocean acidification (Q1) more highly than did the policymakers (adjusted $p < .001$), whereas the policymakers ranked bycatch effects (Q7), restoration effectiveness (Q9), risk assessment for

Table 3. The top 10 priorities of the participants in different self-reported sectors.

Rank	Federal government (*n* = 78)	State or local government (*n* = 165)	NGO (*n* = 32)	Private business (*n* = 14)	Seafood industry (*n* = 15)	Commercial fishery (*n* = 36)
1	Ocean acidification	Monitoring cumulative effects	Ocean acidification	Bycatch effects	Local ecological knowledge	Local ecological knowledge
2	Monitoring cumulative effects	Ocean acidification	Monitoring cumulative effects	Monitoring cumulative effects	Risk assessment for governance	Ocean acidification
3	Bycatch effects	Restoration effectiveness	Ocean literacy messages	Restoration effectiveness	Aquaculture effects	Monitoring cumulative effects
4	Risk assessment for governance	Bycatch effects	Bycatch effects	Ocean acidification	Ocean acidification	Bycatch effects
5	Coral-reef management strategies	Risk assessment for governance	Restoration effectiveness	High-seas governance	Bycatch effects	Aquaculture effects
6	Restoration effectiveness	Ocean literacy messages	Upland hydrology effects on oceans	Local ecological knowledge	Monitoring cumulative effects	Restoration effectiveness
7	Ocean literacy messages	Sea-level rise and vulnerable coasts	Local ecological knowledge	Ocean literacy messages	Restoration effectiveness	Risk assessment for governance
8	Sea-level rise and vulnerable coasts	Uncertainty in modeling	Sea-level rise and vulnerable coasts	Risk assessment for governance	Ecosystem-service-valuation implications	High-seas governance
9	Upland hydrology effects on oceans	Coral-reef management strategies	Coral-reef management strategies	Management capacity of human communities	High-seas governance	Ocean literacy messages
10	Shifting ecological baselines	Upland hydrology effects on oceans	Risk assessment for governance	Information for sustainable food choices	Polar oil spills	Information for sustainable food choices

governance (Q11), and shifting ecological baselines (Q16) more highly than did the scientists (all adjusted $p < .001$; figure 1a). The resource users strongly favored local ecological knowledge (Q20; adjusted $p < .001$), as well as bycatch (Q7; adjusted $p < .001$), risk assessment (Q11; adjusted $p = .002$), and aquaculture (Q5; adjusted $p = .007$), and ranked ocean acidification (Q1; adjusted $p = .007$) and monitoring cumulative effects (Q2; adjusted $p = .02$) lower than the scientists did (figure 1b). The resource users ranked local ecological knowledge (Q18; adjusted $p < .001$) and aquaculture (Q5; adjusted $p = .01$) significantly higher than the policymakers did, and the policymakers ranked MPAs (Q10), coral-reef management strategies (Q3), and sea-level rise and vulnerable coasts (Q8) higher than the resource users did (all adjusted $p < .001$). The policymakers' median ranks of monitoring cumulative effects (Q2) and restoration effectiveness (Q3) were higher than the resource users', but the high variance in within-group rankings meant that between-group differences were not significant (adjusted $p = .67$ and .17 respectively; figure 1c).

PCA was performed on the questions appearing in the top five priorities for the scientists, the policymakers, or the resource users: ocean acidification (Q1), monitoring cumulative effects (Q2), coral-reef management (Q3), aquaculture effects (Q5), bycatch effects (Q7), sea-level rise (Q8), restoration effectiveness (Q9), risk assessment for governance (Q11), and local ecological knowledge (Q18). The first axis of PCA (19.7% explained variance) revealed separation between scientists and resource users influenced by prioritization of ocean acidification and local ecological knowledge (figure 2). The second axis of PCA (14. 9% explained variance) did not show obvious distinction between groups (figure 2) but may indicate variation within groups driven by prioritization of aquaculture, coral-reef management (both positively correlated to PC2; table 4), and risk assessment (negatively correlated to PC2; table 4). Indeed, the majority of the variance was explained by additional variables (table 4) that did not provide insight into the separation between groups.

Dividing the scientists by discipline for these same questions revealed greater overlap between the social and natural scientists and the stakeholders than the physical scientists (supplemental appendix S3). This was corroborated by pairwise tests: The physical scientists significantly differed from the managers for 18 questions and the users for 21, the natural scientists significantly differed from the managers for 16 questions and the users for 17, and the social scientists significantly differed from the managers for only 8 questions and the users for 6; however, this may be in part because of relatively smaller sample sizes among the social scientists and resource users.

Pushback from the respondents

Several respondents, most of whom were commercial fishermen, provided feedback about the survey and survey questions via comments, write-in questions, and email and phone conversations with the corresponding author (selected comments in box 1). These comments revealed frustration with the wording and content of the questions and mistrust of the survey and of the authors. The question about job creation (Q25) was especially contentious and may have alienated the respondents; perhaps unsurprisingly, this was the only one of the original 67 questions taken

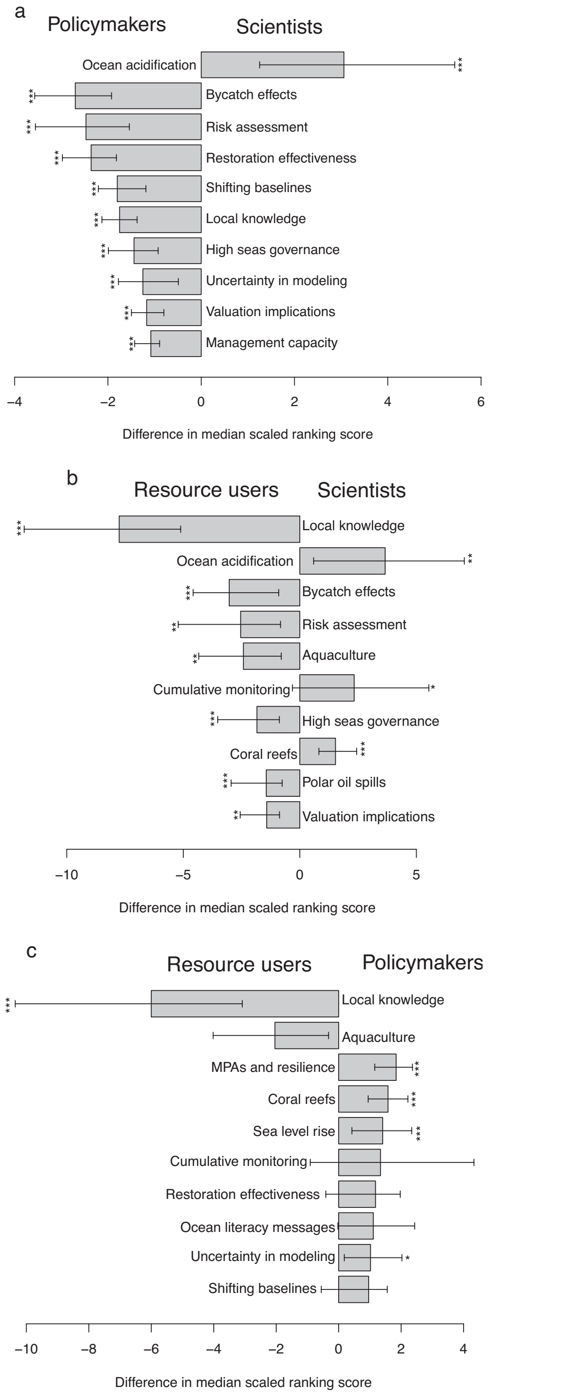

Figure 1. The 10 questions with the biggest significant differences in median scaled ranking score among (a) scientists and policymakers, (b) scientists and resource users, and (c) policymakers and resource users are shown in decreasing order. The positive values indicate that scientists—or in (c), policymakers—had a higher median rank of that question. The error bars represent 95% confidence intervals based on bootstrapping with 1000 iterations. statistical significance is based on Bonferroni-adjusted p-values: *p < .05, **p < .01, ***p < .001. The questions with significant p-values but large error bars are likely a result of highly skewed distributions of question ranking scores.

directly from an academic article (Borja et al. 2013) rather than bottom-up horizon scanning or research prioritization exercises. This mistrust and frustration may have accounted for relatively lower participation among resource users than among policymakers.

Discussion

The prioritization of research questions was broadly similar across groups, but certain areas of disagreement and the reactions to the structure and language of the survey reveal that for cross-sectoral collaboration, agreement on important questions is likely secondary to the manner and environment in which those questions are asked. The top and bottom priorities were similar across groups, with ocean acidification, monitoring cumulative impacts, bycatch reduction, and habitat restoration in the top ranked 10 for every group. The key differences were that the scientists prioritized ocean acidification significantly more highly than either stakeholder group did; the policymakers prioritized questions about habitat restoration, bycatch, and precaution more highly than the scientists or resource users did; and the resource users strongly emphasized local ecological knowledge. The scientists' priorities were more similar to the policymakers' than to those of the resource users, and the social and natural scientists were more aligned with the stakeholders than with the physical scientists. The PCA results also hint at variation within groups, which would be a possible future direction of study with a larger sample size.

These results are similar to previous findings in stakeholder priority research. An interview-based study of stakeholder valuation of coral reefs showed that the fishermen were more distinct from the scientists than from the managers (Hicks et al. 2013), and a prioritization exercise with Swiss policymakers revealed similar themes (ecological stressors, habitat concerns, literacy and outreach, monitoring) in top-ranked questions and write-in questions (Braunisch et al. 2012). A study of priorities among US scientists and policymakers used a similar open sampling method but demonstrated no significant differences in prioritization between the scientists and the policymakers, but the questions used in that study were explicitly designed to relate to policy, whereas the questions in this research covered a broader scope (Rudd and Fleishman 2014).

It is unsurprising that there would be some differences in the ocean issues stakeholder groups consider most important, because these groups may have different mandates, motivations, and values. Indeed, the patterns of prioritization in this study seem to reflect these motivations and mandates, with scientists choosing ocean acidification and cumulative stressors—topics that are currently emphasized in funding and publication—and policymakers selecting topics relevant to legal and political frameworks such as restoring critical habitat or using the precautionary principle. The inclusion of polar oil spills as a top priority for the seafood-industry respondents seems unexpected but

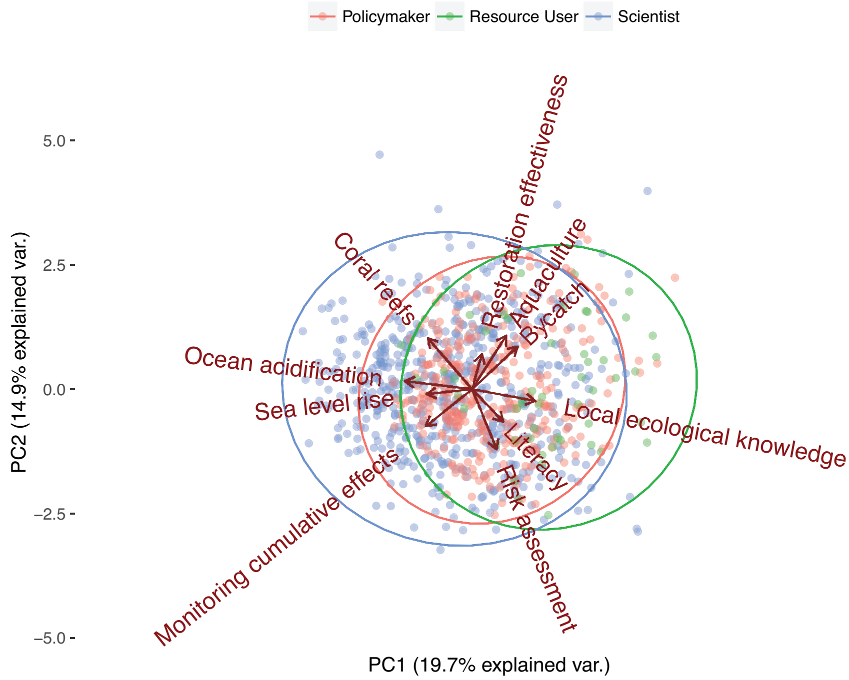

Figure 2. A principal component analysis showing variation in stakeholder groups based on the prioritization of key questions, defined as those in the top five priorities of any stakeholder group. The ellipses represent a 95% probability zone.

may reflect seafood impacts from lower-latitude oil spills such as Deepwater Horizon or lingering concerns from the Exxon Valdez spill. It is also logical that social scientists would be similar to other stakeholders, because human-centered studies pertain to the management, economy, and interactions of people that also concern and drive policymakers and fishermen. Natural scientists' studies may also be more relevant to the biological resources subject to both management and fishing, whereas physical science may be less directly linked.

The overall similarities in the top priorities may reflect effective communication between stakeholder groups: Scientists' findings, when publicized, have raised awareness among other stakeholder groups of the major issues affecting the oceans. Alternatively or in combination, policymakers' and fishermen's needs and experiences have influenced scientific research directions or funding emphases. Scientists may consider themselves at the leading edge of human knowledge, but fishermen's comments bespeak the sentiment that the change they're observing on the water outpaces scientific research and publication (see box 1, comment 2). Collaboration, therefore, is not solely a matter of effective scientific communication but also of dialogue, because all groups may benefit from hearing and understanding each other's priorities.

The fishermen's qualitative responses to the survey and questions shed further light on how different groups' priorities might best be put into conversation. The frustration and mistrust with the survey format, academic language, and perceived conservationist assumptions underlying the questions, as well as comments about scientists in general, reflect a history of perceived opposition between scientists and fishermen not easily overcome by an impersonal online invitation to rank pre-formed questions. More open formats such as discussions or workshops, convened only after dedicated efforts to build relationships and trust, might be more appropriate for soliciting broad stakeholder input. Such discussions would be most successful with careful attention to avoiding jargon and including diverse worldviews. Participatory and iterative stakeholder meetings involved in Canadian and US marine spatial planning are examples of how this process might operate (Gopnik et al. 2009, Jones et al. 2010, Gopnik et al. 2012). Such methods are time consuming and less quantifiable than this survey method, but they are ultimately more in the spirit of cross-sectoral, participatory, solutions-oriented collaboration.

Caveats. This study was primarily limited by our sampling method, because the use of nonprobability sampling techniques to reach a larger group of stakeholders carries the risk of bias and patchiness in the sample. Our relatively small and geographically patchy sample size among resource users may reflect strongly held opinions of a few; therefore, our results may not be representative of priorities across the full spectrum of fisheries-sector stakeholders. Furthermore, additional studies including other resource-use sectors, such as aquaculture, tourism, shipping, and energy, may allow comparisons among resource-user groups, as well as more broad characterization ocean resource-user priorities. Further studies with more diverse ocean resource users, perhaps including recreational users, would bring more voices to the conversation and provide a fuller picture of how ocean resource users prioritize ocean issues; however, as we discussed above, open-ended, discussion-based platforms may be more effective and appropriate than an online survey.

The distribution of LCA-selected questions also led to a skewed distribution of rescaled US scientist ranks. Ten of the selected questions were ranked relatively low in priority among the original sample of scientists (ranked 50 or lower out of 67—there was generally a higher level of consensus among the scientists for the highly ranked questions; see Rudd 2014), so the rescaling process may have amplified the differences between the questions, leading to relatively

Table 4. The explained variance and factor loadings from the principal components analysis performed on the questions appearing in the top five priorities for scientists, policymakers, or resource users.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Proportion variance explained	0.20	0.15	0.13	0.12	0.09	0.09	0.08	0.07	0.06	0.03
Cumulative proportion	0.20	0.35	0.47	0.59	0.68	0.77	0.84	0.91	0.97	1.00
Ocean acidification	–0.48	0.07	–0.34	–0.05	0.10	–0.10	0.29	0.19	–0.63	0.32
Local ecological knowledge	0.45	–0.10	0.11	–0.12	0.14	–0.02	0.81	0.08	0.14	0.25
Bycatch effects	0.33	0.35	–0.38	–0.10	–0.31	0.13	–0.05	–0.63	–0.13	0.28
Monitoring cumulative effects	–0.33	–0.30	–0.16	–0.42	–0.20	–0.48	–0.03	–0.14	0.47	0.29
Coral-reef management strategies	–0.32	0.42	–0.18	0.20	–0.12	0.46	0.13	0.28	0.53	0.22
Sea-level rise and vulnerable coasts	–0.32	–0.04	0.61	0.12	0.27	0.19	–0.00	–0.48	–0.03	0.41
Aquaculture effects	0.24	0.44	–0.01	–0.25	0.58	–0.25	–0.36	0.22	0.07	0.31
Ocean literacy messages	0.22	–0.27	–0.13	0.73	–0.09	–0.27	–0.17	0.12	0.03	0.45
Risk assessment for governance	0.18	–0.49	–0.07	–0.35	–0.04	0.58	–0.29	0.25	–0.10	0.33
Restoration effectiveness	0.07	0.29	0.52	–0.15	–0.63	–0.17	–0.06	0.33	–0.19	0.21

much higher-ranking scores for ocean acidification (Q1) and monitoring cumulative effects (Q2) and much lower scores for the remaining questions than they did for the stakeholders. This could not be remedied without resurveying the scientists, so multivariate methods such as PCA or comparison of the ordering of the questions may be more informative than evaluating differences in the numerical ranking scores.

Conclusions

The relatively high level of agreement validates these questions as effectively capturing key issues for stakeholders, but the reactions to the questions impugn the way in which the questions were worded and asked. For future studies with stakeholders and resource users, an interview or discussion-based approach with an emphasis on building relationships and trust (Sutherland et al. 2009, 2011, Fleishman et al. 2011) might be more appropriate. The frustration with the technical language and assumptions embedded in the questions highlights the communication problem that may be at the heart of priority misalignment: The jargon that builds trust among groups of scientists by conveying precision may not only exclude other groups but also erode trust between them.

Responses from resource users also expressed considerable frustration that their voices are not being heard. A key aspect of transdisciplinary solutions-oriented research is nonacademic stakeholder participation in knowledge creation to increase engagement, accountability, and ownership (Mauser et al. 2013). The use of alternate forms of knowledge, from interviews to collaborative field projects to active participation and the coproduction of knowledge, is small but growing in conservation research (Huntington 2000, Lynam et al. 2007, Beaudreau and Levin 2014). Although some have argued that we are in the middle of a paradigm shift toward wider acceptance of local knowledge (Brook and McLachlan 2008, Thornton and Scheer 2012), ensuring credibility and determining how and when local knowledge can contribute to conservation solutions remain major challenges.

The goal of improved communication and knowledge coproduction is not necessarily to align priorities. A disconnect in priorities may be a reflection of fundamentally different roles, values, and mandates, and problems arise not because differences exist but because of a failure to acknowledge them or to recognize that other groups' priorities may also be valid. Listening to, understanding, and respecting other groups' priorities can facilitate more effective transdisciplinary collaboration and the creation of solutions.

These results reinforce the need for interdisciplinary research that includes or emphasizes social science, the coproduction of knowledge alongside sectors outside academia, and interdisciplinary and transdisciplinary programs and training for marine conservation (Ciannelli et al. 2014). Interdisciplinarity in teams and in individuals is essential as we tackle conservation issues at the complex interface of ecology and society (Daily and Ehrlich 1999, Balmford and Cowling 2006).

This study, the first to quantitatively compare US scientists' and stakeholders' priorities of ocean and coastal questions and to explicitly address fisheries-sector resource-user priorities, reveals encouraging agreement across sectors. It also, however, brings into focus that scientists not only need to engage broader stakeholders in the discussion for conservation research but also think about *how* to engage them. Language, norms, and goals are not necessarily shared across groups, and solutions-oriented interdisciplinary or transdisciplinary research requires that we recognize and respect differences in worldview and be mindful of how we might even inadvertently exclude or alienate groups. We hope that by illuminating key priority similarities and differences, this study helps open broader and more productive dialogue among ocean stakeholders and foster transdisciplinary ocean solutions.

Box 1. Pushback from fishermen (original wording intact).

"Is this legit or some ploy by someone we do not want to deal with"

"I'm a fisherman all my income comes from fishing and feel that over regulation has effected my life . . . the science is always two years behind what is happening at sea I think their out to put small boat fishermen out like the small farmers"

". . .the survey pigeonholes you to positions . . . that have not been agreed to or accepted by fishermen . . . a tremendous amount [of] hubris or assumptions that preconceived positions are universally accepted by all."

"The questions are too academically worded. I won't have this coming out of my office. I just can't see sending this out [to the fleet]. I think it would do more harm than good."

"Very few scientists are honest. Trust is hard to earn in the real ocean."

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Supplemental material

Supplementary data are available at *BIOSCI* online.

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Julia G. Mason (jgmason@stanford.edu) is a PhD candidate and Larry B. Crowder is a professor at Stanford University Hopkins Marine Station in Pacific Grove, California. Mason studies the interacting effects of climate and management on fisheries resilience. Crowder, also the science director at the Center for Ocean Solutions, in Monterey, California, works with interdisciplinary approaches to marine conservation. Murray A. Rudd is an associate professor in the Department of Environmental Sciences at Emory University, in Atlanta, Georgia. His research focuses on conservation social science and the environmental science–policy interface. The authors declare no conflict of interest.