npj | ocean sustainability

Article

https://doi.org/10.1038/s44183-024-00086-2

Risks of competing discourses of scientific responsibility in global ocean futures

Check for updates

Sarah Lawless[1,2,3,4] ✉, Jacqueline Lau[4,5], Robert Streit[1,6] & Tiffany H. Morrison[1,6,7]

Accelerated innovation in climate-impacted oceans is outpacing standards of scientific responsibility. Standards of responsibility are critical because they shape research agendas, funding flows, scientific practice, and how innovations are regulated. Here, we examine responsibility debates among 243 marine scientists and end-users proposing, trialling and/or implementing 76 innovations for climate-impacted oceans. We identify three distinct discourses: 'science outside society', 'science for society' and 'science with society'. Competition within and across these discourses reveals heightened tensions between the need to protect scientific autonomy and freedom, and moral duty to ensure socially just and desirable ocean futures. Without thorough debate and oversight, the wide-reaching power of such unresolved tensions could propel marine science and ocean futures into volatile ethical and moral territory. Better connection and articulation of standards of responsibility with scientific motivations, practices, and funding are key to ensuring the transparency and accountability required to progress equitable and sustainable oceans.

'The ocean we need for the future we want' is both a compelling manifesto for the United Nations Decade of Ocean Science for Sustainable Development (2021-2030) and a clear articulation of future-oriented scientific responsibility. Since 2021, the Ocean Decade has provided an international platform for scientific research that supports improved conditions for an equitable and sustainable planet, aligned to achieving the Sustainable Development Goals by 2030[1]. Indeed, by foregrounding the moral obligation of science to pursue sustainable, desirable, and just futures, the Ocean Decade embodies the longstanding pursuit of science for societal good. However, the bounds of responsible marine science and innovation are now being stress-tested as the push for innovative ocean 'solutions' outpaces decisions about moral obligations and the ethics of responsibility[2–4].

Recent scientific responses to rapid, complex and uncertain ocean change have culminated in a raft of 'new and emerging' ocean innovations worldwide to boost the resilience of marine systems to global heating[5,6]. Examples of climate mitigation innovations include ocean alkalinity enhancement to accelerate oceanic carbon uptake, and restoration, conservation and aquaculture of coastal habitats and species for carbon sequestration[6–8]. Responses promoting climate adaptation include assisted marine animal and plant migration, marine climate refuge protection, and solar-radiation control[4,5]. These innovations have been described as 'new frontiers' of ocean science, each posing a myriad of visions and challenges for science and policy[9].

Such new frontiers are challenging notions of scientific responsibility. In marine and climate science, responsibility is influenced by scientists' values and their perceived role in and to society[10,11]; the assumed relationship between humans and nature[12]; specific ocean philosophies, ontologies and epistemologies[13]; and multiple moralities that shape scientific decisions around climate action[14]. These different positions, values, knowledge systems, and morals shape how science is problematized and evaluated, the end goals that are pursued, and ideas about how science and innovation should be governed (i.e., regulated and funded)[15–18]. As such, notions of responsibility directly influence how ocean science and innovation shape possible futures[19]. However, it is unclear how notions of scientific responsibility (henceforth 'discourses') are shaping new and emerging ocean innovations. This gap requires urgent attention because collectively failing to reflect upon the power of these discourses among the scientific community and new ocean innovations risks propelling ocean futures into volatile ethical and moral territory[20,21]. Explicitly articulating and connecting ideas about responsibility to scientific motivations, agendas, funding, and power is

[1]College of Science and Engineering, James Cook University, Townsville, Queensland, Australia. [2]Australian Institute of Marine Science, Townsville, Queensland, Australia. [3]AIMS@JCU, Division of Research and Innovation, James Cook University, Townsville, Queensland, Australia. [4]Centre for Sustainable Tropical Fisheries and Aquaculture, James Cook University, Townsville, Queensland, Australia. [5]College of Arts, Society and Education, James Cook University, Townsville, Queensland, Australia. [6]School of Geography, Earth & Atmospheric Sciences, University of Melbourne, Melbourne, Victoria, Australia. [7]Environmental Policy Group, Wageningen University and Research, Wageningen, The Netherlands. ✉e-mail: sarah.lawless@jcu.edu.au

critical to ensuring scientific transparency, accountability, and benefit to ocean systems and global society.

Here, we examine global survey data to identify responsibility discourses articulated by 243 scientists and practitioners proposing, trialling and/or implementing innovations to mitigate or delay climate impacts upon oceans and marine systems (henceforth 'ocean innovations', Fig. 1). Our survey recruitment strategy, undertaken in 2023, primed for 'new and emerging' ocean innovations (see Methods section), including marine carbon removal strategies, assisted evolution of species, and cloud brightening, which are touted as some of the most 'promising'[8], 'immature but potentially crucial'[22], 'experimental'[5], 'hyped'[6], and 'costly' innovations[23]. We used discourse analysis to understand views of responsibility associated with these often contested and sometimes politicised innovations. In structuring our analysis, we drew on established principles of responsibility across the sciences, including in research and public policy[17,24–26]; ecology and biology[2,20,27,28]; philosophy[21,29]; and science and technology studies[16,30].

Results

We asked survey respondents ($n = 243$) to identify an innovation for climate-impacted oceans they were most familiar with ($n = 76$). We then classified these 76 innovations into five categories based on their overarching goals (Fig. 1, Supplementary Table 1). In describing these innovations, the 243 scientists and practitioners surveyed revealed clear tensions of scientific responsibility that oscillated between protecting scientific autonomy and freedom at one extreme, and moral duty to ensure socially just and desirable futures at the other. In analysing our data, we found that these tensions emerged as three distinct discourses; 'ocean science outside society'; 'ocean science for society'; and 'ocean science with society' (Fig. 2). Within these discourses, we found that respondent perspectives varied according to their views on i) the role of science; ii) the role of regulations; iii) approaching social uncertainty and risk; iv) approaching scientific problems; v) the role of the public; and vi) the relationship between research and application (Box 1). We also found evidence of unspoken competition across discourse proponents holding affirmative views and discourse critics holding negative views, highlighting the cross-cutting need for more vigorous and open debate about scientific responsibility in ocean-climate innovation.

Ocean science outside society discourse

Survey respondents expressing views aligned with the 'ocean science outside society' discourse (henceforth 'discourse proponents') indicated that ocean science and innovations were inherently beneficial, value-neutral and undertaken objectively (Table 1). Discourse proponents viewed science as a public good, which warranted an unencumbered scientific freedom and a 'right' to generate knowledge. This view was characterized by appeals for scientific autonomy to conduct experiments, and calls to curtail institutional, regulatory, and permitting requirements related to ocean innovations (Table 1 rows A, B).

Proponents of the 'ocean science outside society' discourse exhibited an inherent assumption that science always serves society (Table 1. row C). For instance, one respondent asked "Why do we need regulation when we are improving an area?" (artificial habitat manipulation). When questioned about the data used for innovation feasibility and risk assessments, proponents expressed an ambivalence to social considerations, which were underpinned by the view there is an inherent social risk, or disservice to society, of not intervening (Table 1. row C). Respondents critical of this position (henceforth 'discourse critics') were wary of the unreflexive assumption that ocean science and innovation is always good (Table 1. row A). Discourse critics rejected the idea that science is apolitical, objective or value-neutral; they perceived a privileging of technofixes driven by neoliberal incentives principally concerned with job creation and wealth accumulation (Table 1. row A). Referring to artificial habitat manipulation, a respondent reported the current system of regulating and funding "operates as a black box where a node leader can disburse research 'for the boys'. The consequence is that important research to guide decision making is not undertaken, regulators are disempowered, and suboptimal decisions may be made about our environment."

Critics also signalled that a neoliberal push and fixation with technological 'solutions' meant that scientists could abrogate their responsibility for addressing the root causes of climate change (Table 1 row D). A critic argued the biggest risk of coral restoration is "cancelling the ongoing decline of coral reefs with good news stories that clever scientists can regrow corals in the face of anthropogenic climate change" (regrowing targeted underwater species). Scientists and practitioners operating under this discourse were said to be supporting "greenwashing for marketing value and for the researcher it is a continued unethical program to secure funding" (regrowing targeted underwater species). Critics pointed out that framing science as neutral was dangerous and led to investing time and money into technology without considering broader system-level impacts. By contrast, proponents suggested that science should only concern scientists, with limited space for non-science users (Table 1 rows E, F). Critics argued that

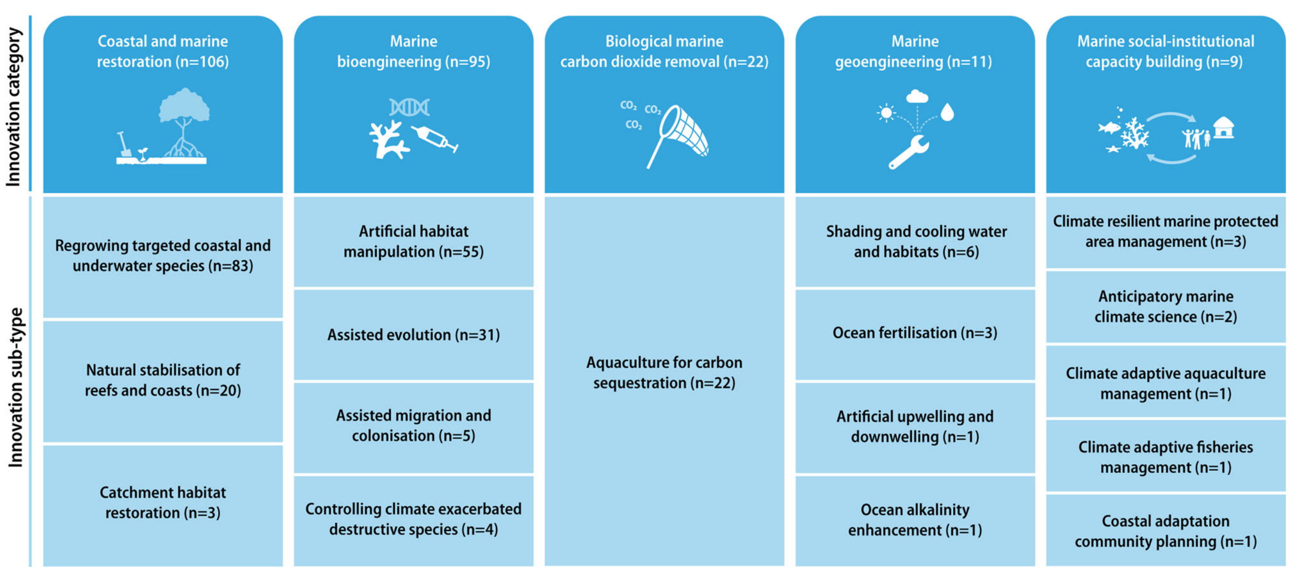

Fig. 1 | Innovations for climate-impacted oceans identified by global survey respondents (n = number of responses, total responses $n = 243$). Respondents identified 76 unique innovations, which we grouped into five categories based on their overarching goals (see Supplementary Table 1 for expanded description).

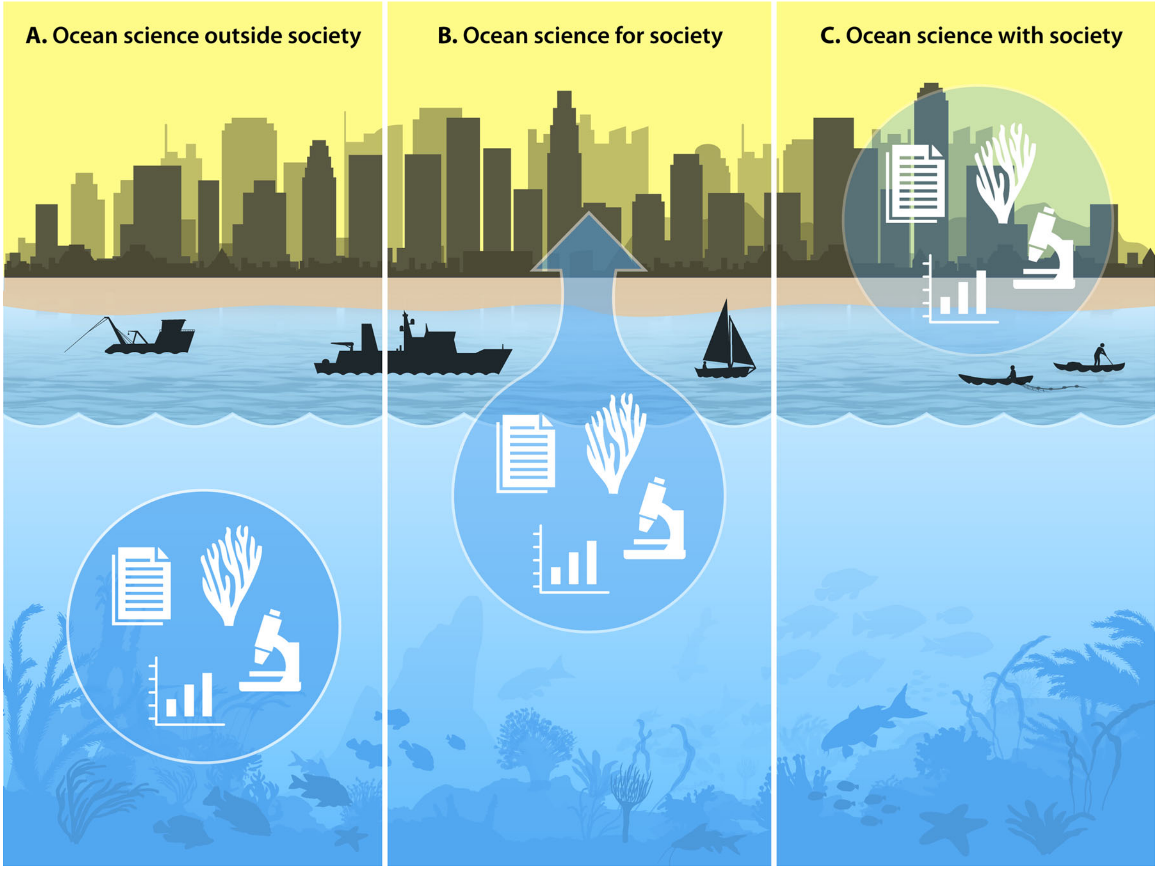

Fig. 2 | Discourses of responsibility among 243 scientists and practitioners proposing, trialling and/or implementing 76 bio-technical and social innovations for climate-impacted oceans. **Panel A** the 'Ocean science outside society' discourse entails that (**a**) science is apart or detached from society; (**b**) scientific innovation is objective and value-neutral; and (**c**) science, and therefore scientists, require autonomy and freedom to generate knowledge. **Panel B** the 'Ocean science for society' discourse contends that (**a**) science is unidirectional, whereby science is 'delivered' to, and received by society; (**b**) science and scientists provide public value and good; and (**c**) science lives up to public demands for innovation. **Panel C** the 'Ocean science with society' discourse emphasizes (**a**) science as co-designed and co-produced with societal actors; (**b**) long-term benefits for society; and (**c**) moral and ethical obligations for scientists to contribute toward socially sustainable and just futures.

Box 1 | Views of responsibility varied among scientists and practitioners working on innovations for climate-impacted oceans across six normative dimensions (henceforth 'discourse features')

1. ***The role of science***: Views about the relationship science should have with society; provision of public goods; and responsiveness to societal needs.
2. ***The role of regulations***: Views about the function of regulatory, permitting, and institutional mechanisms for ocean science and innovation.
3. ***Approach to social uncertainty and risk***: Views about the type and extent societal implications should be anticipated, measured, and addressed.
4. ***Scientific approach to problem characterisation***: Views about how problems should be identified and addressed, including by whom this should be determined, and which knowledge and data is valued.
5. ***The role of the public***: Views about the role and space for public needs, concerns, and ideas.
6. ***The relationship between research and application***: Views about the interaction research should have with implementation, including the relationship between science and non-science users.

positioning the public outside of knowledge creation led to public disengagement as well as misleading views of the efficacy of ocean science, "Assisted breeding of corals gives the general public the mistaken impression that scientists can effectively repair damaged reefs. That reduces a sense of urgency for reducing carbon emissions" (assisted evolution of marine species).

Ocean science for society discourse

Proponents of the 'ocean science for society' discourse (Table 2) generally agreed that science with perceived public value should be developed and then delivered to society. Yet, discourse critics argued that what was considered a 'public good' was too narrow. A critic contended there is a need for "The conservative culture of governments and scientific funding bodies to

Table 1 | Features of the 'Ocean science outside society' discourse as represented by differential views of proponents and critics

	Discourse proponent		Discourse feature	Discourse critic	
	Illustrative quote(s)	View		View	Illustrative quote(s)
A	*"Institutional barriers prevent novel techniques from being trialled"* (regrowing targeted underwater species).	Science is objective, value-neutral and inherently good. Scientists should have scientific autonomy and the right to research.	**Role of science**	Science is value-laden and subjective. Science and scientists do not necessarily serve society.	*"[Scientists are only concerned with] further research funding and career advancement"* (artificial habitat manipulation).
B.	*"[We need] less policy interference, more funding into implementation"* (natural coast and reef stabilisation).	Regulation should enable not restrict or interfere with scientific experimentation and autonomy.	**Role of regulation**	Ocean science and innovation needs greater regulation and controls to reign in irresponsible practice.	*"Better controls on the agencies involved to ensure best practice. There's lots of cowboys out there with good intentions but limited skill, expertise and understanding [of best practice]"* (artificial habitat manipulation).
C.	*"[A] missed opportunity is to not avail society with the ability to rectify the increasing pressures on some of the world's most valuable ecosystems and …contribute to the world's ecosystem services"* (climate adaptive aquaculture management).	Scientific ocean innovations always provide service to society, therefore, there is no need to consider social risk or uncertainty. The cost of not trialling innovations outweighs any other social risks.	**Approach to social uncertainty and risk**	When scientists abrogate their responsibility to provide societal benefits there is increased risk of unintended social and ecological consequences.	*"Social, cultural, and economic feasibility do not seem to be on the radar currently"* (assisted evolution of marine species). *"[I am] fairly sure that social data are not used [to assess social risk and impacts]"* (assisted evolution of marine species).
D.	*"The cost of doing nothing is huge"* (controlling climate-exacerbated destructive species). *"[A great risk is] not acting fast enough or allowing ideas the opportunity to be piloted"* (natural coast and reef stabilisation).	Better to pursue technocratic approaches than no approaches to address climate problems. Science prioritizes Western scientific understanding for problem identification.	**Scientific approach to problem characterisation**	Science is coerced by political agendas and neoliberal incentives and can privilege short-term 'techno' fixes.	*"[Science facilitates] short-term, 'sexy' projects like coral out-planting and 3D printing"* (natural coast and reef stabilisation). *"I feel some players are still in large scale piloting as a chance to gain significant dollars"* (natural coast and reef stabilisation).
E.	*"The worst kind of data is 'Citizen Science' … untrained amateur observations with a massive bias towards specific outcomes and no integrity … Sources that should guide assessments are ecological studies and physiological research which allows predictive modelling …"* (artificial habitat manipulation).	Science should only be informed by scientists.	**Role of public**	The public are disengaged from innovation but should be included.	*"Communities are usually consulted or informed well after plans have already moved ahead or received investment"* (natural stabilisation of reefs and coasts). *"…people feel helpless to dispute it [innovation]"* (artificial habitat manipulation).
F.	*"Often the gap between scientific research/pilot scale implementation is difficult to extrapolate to landscape-scale restoration and monitoring; there can be a distinct gap between researchers and practitioners and their interests"* (regrowing targeted underwater species).	Science is connected to innovation deployment but detached from non-science users.	**Relationship between research and application**	Innovation development is insufficient in planning for adaptive or post-deployment measures.	*"[The biggest risk is] unintended consequences to the environment and marine dependent humans [and] major investment in an unverifiable or potentially harmful mitigation option"* (ocean alkalinity enhancement).

Table 2 | Features of the 'Ocean science for society' discourse as represented by differential views of proponents and critics

	Discourse proponent		Discourse feature	Discourse critic	
	Illustrative quote	View		View	Illustrative quote
A.	*"Best available science should inform the collective decisions, not dictate it"* (catchment habitat restoration).	Science provides perceived public value and good that is delivered to society in a way that brings return on investment.	**Role of science**	Science can be undertaken to appease vested interests of powerful actors.	*"[Scientists] are asking questions posed by government, non-government, or industry bodies for their own benefit … Scientists have turned into performing seals … [handing] control over to rich industries or agencies to use science for their own purposes"* (artificial habitat manipulation).
B.	*"Guidelines of different levels of environmental risk and what is 'acceptable' and what is 'unacceptable' for a new venture [are needed]"* (aquaculture for carbon sequestration).	Regulation provides scaffolding to ensure science engages with technological, ecological, and social implications and creates a safe and investable space for research.	**Role of regulation**	There is an overreliance on regulations and regulating agencies that are ill equipped to deal with novel innovation implications. There are limited independent social and ethical assessments of innovations.	*"The most significant issue is the weak governance. Lack of long-term policy goals (State policies), and budget and staff restrictions are limiting the capacity to achieve sound goals"* (regrowing targeted coastal species).
C.	*"Climate resilience is the main goal… other benefits from ecosystem-based adaptation include carbon sequestration, adaptation, alternative livelihoods"* (natural stabilisation of reefs and coasts).	Social implications refer to social and cultural risk minimisation. Social risks can be quantitatively modelled or measured. Regulatory controls and/or permit systems are responsible for accounting for risk.	**Approach to social uncertainty and risk**	Social implications are not adequately addressed (i.e., narrow audiences, methods, or metrics). Science can seek to gain social license more so than ensuring sustained societal impact.	*"[There is an absence of social or ecological feasibility assessments because] the goals are simply to sell a product to the public and governmental bodies to gain funding and prestige"* (artificial habitat manipulation).
D.	*"There is awareness that all these data are necessary [i.e., economic; traditional ecological use; cultural or social value] but only oceanographic, physical, biological, cost information has been incorporated"* (ocean alkalinity enhancement).	Addressing climate problems prioritises technological, ecological, and economic feasibility. Problems addressed by innovations are informed by Western scientific problem lens.	**Scientific approach to problem characterisation**	Innovations are sold to the public as 'solutions', yet are narrowly contained, short-term, and symptomatic fixes. Prioritises technological, ecological, and economic feasibility.	*"[There is] over-hype that growing certain species (e.g., seaweeds) will 'save' the reef/ oceans/ planet … and the biggest intervention, reducing carbon emissions, is not receiving the attention it deserves…"* (regrowing targeted underwater species).
E.	*"[Public engagement occurs] via regulatory processes (e.g., permitting, mandatory feedback periods)"* (regrowing targeted underwater species).	Opportunities for public engagement should occur via formalized channels. The public should be informed and/or consulted post-design.	**Role of public**	Limited opportunity for public to influence the type and direction of innovations.	*"[There is a need to] open up the community discussion on the goals and experimental designs"* (assisted evolution of marine species).
F.	*"Stakeholder engagement is important for successful project development and site selection"* (artificial habitat manipulation).	Science is developed, then the public is engaged for delivery or site selection.	**Relationship between research and application**	Limited coordination and information sharing between stakeholders.	*"Silos of science, policy and implementation not aligning has hindered progress"* (natural stabilisation of reefs and coasts).

think of broader opportunities that development can achieve rather than jobs and wealth" (climate adaptive aquaculture management). Critics also suggested influential vested interests that may not serve society were prominent in the development of new and emerging ocean innovations, reportedly reinforced by "output orientated donor funding" (regrowing targeted coastal species). Critics called for improvements in the way science and ocean innovation were governed through greater transparency of "information sharing [and] creation of best practice standards" (artificial habitat manipulation) and vetting all innovation proposals independently "based on environmental, economic and societal criteria, with a clear risk-benefit analysis" (artificial habitat manipulation) (Table 2 rows A, B).

Proponents saw regulators and permitting systems as principally responsible for ensuring oversight of technological, ecological, and social implications; issues they considered to be adequately considered and mitigated (Table 2 rows B, C). However, critics reflected on the tendency for problems to be narrowly contained due to innovations being developed in "siloes of science" (natural stabilisation of reefs and coasts) (Table 2 row D). Such problem containment reportedly detracts from addressing broader, system level drivers or impacts "… people have a single driven goal and are not aware of multiple external factors which will impact it" (artificial habitat manipulation). The science for society discourse was also linked to missed opportunities to account for social uncertainty and risk (Table 2. row C). In cases where social risks or impacts were considered, respondents indicated they were contained to those that could be quantitatively modelled or measured. Critics expressed concerns about the lack of social risk, impact, and ethics considerations, including "organisations or individuals moving ahead in a non-rigorous and non-evidence-informed way, with potential for significant reputational risk to the field" (regrowing targeted underwater species).

Proponents reflected on current mechanisms to encourage public and stakeholder engagement, which mostly included formal or regulatory processes set by federal agencies, with public outreach usually occurring post-innovation (Table 2 row E). Yet, critics reported that public consultation processes were in the form of "very limited surveys … [which were] limited to very narrow audiences" (ocean alkalinity enhancement). Several critics argued engagement was focused on gaining social license to operate by "… selling people a magic cure for the problems of climate change and reef decline" (artificial habitat manipulation), generating a false confidence among the public about the capability of innovations to mitigate or adapt to climate impacts (Table 2 row E). Critics also reflected on the limited diversity of people being engaged, specifically citing the need to "be able to meaningfully engage IPLCs [Indigenous Peoples and local communities]" (climate resilient marine protected area management). In addition to identification of key stakeholders, critics reflected on a need to improve processes of engagement and connection with innovation use (Table 2 row F), "Projects should be conducted with appropriate due diligence and full, prior, and informed consent procedures. In reality, [this is] probably unlikely, especially for experimental sites" (regrowing targeted underwater species).

Ocean science with society discourse

The 'ocean science with society' discourse emphasized the need for a greater focus on societal co-creation of innovations, societal co-benefits, and moral and ethical deliberation. Although we found evidence of views aligning with this discourse (Table 3), these were largely aspirational and idealistic rather than reflective of current practice. Proponents perceived a need to ensure clear societal benefits through innovation co-design and co-production with societal actors, including local communities, Indigenous Peoples, and Traditional Owners (Table 3 rows A, D, E). Specifically, proponents highlighted the need for slow, connected, culturally sensitive, inclusive scientific development, with opportunities for capacity transfer and exchange (Table 3 rows E, F). For example, a respondent called for a greater focus on "capacitating local communities so that it [seaweed farming] does not become a one-time project but a diversification of sectors and alternative livelihoods" (regrowing targeted underwater species). Another suggested more inclusive processes would lead to enhanced understanding of social implications, "Because work is just beginning [on novel ocean innovations] there is tremendous opportunity to get inclusion of interested parties correct and examine social systems [as well as] environmental outcomes" (ocean alkalinity enhancement).

In acknowledging the limitations of reliance on external regulations, proponents argued deeper social and institutional mechanisms were needed to ensure that adequate engagement protocols were in place. Examples included protocols to enhance Indigenous leadership and knowledge integration (Table 3 row B); community needs, social impact, or vulnerability assessments; and considerations for locally determined economic species values, local food security, traditional cultural uses, and on-the-ground capacity to lead innovations (Table 3 row C). Proponents also emphasised the need for "transdisciplinary approach[es]", including those that overcome a lack of "social science information" (regrowing targeted underwater species). Proponents cited a need for long-term scalable solutions (Table 3 row D), "We don't know the real impacts of these interventions and if they are going to be effective in the long term" (natural stabilisation of reefs and coasts). Proponents were also conscious that current innovations were symptomatic responses to deep-rooted problems. A respondent reported "[There is] too much focus on the erroneous idea that small-scale interventions will 'save the planet', rather than educating and inspiring people to become more involved in solving the root cause [of climate change]" (artificial habitat manipulation).

Critical views of the 'ocean science for society' discourse reflected unresolved concerns related to applying aspirational notions of responsibility. Critics specifically cited structural limitations to enacting the values articulated in this discourse, such as the rigidity of established systems of funding, blurred regulatory responsibilities, lack of institutional will, time constraints, limited access to social and ethical expertise, and uncertainty around capacity exchange (Table 3 rows A, B, C, F). Critics also acknowledged broader system level challenges in embracing a pluralism of world-views and generating cohesion for desired futures among diverse stakeholders (Table 3 row D). Importantly, these critics highlighted that the aspirational nature of such goals posed an inherent risk by deferring responsibility to local groups, and thereby abrogating scientists from public accountability (Table 3 row E).

Discussion

As climatic impacts on oceans worsen, ocean innovations are being rapidly deployed and upscaled across tropical, temperate, and polar regions. Discourses of responsibility, and the normative value-frames upon which they are based, will shape the futures that these innovations are likely to bring about[17]. Our examination of notions of responsibility among scientists and practitioners proposing, trialling and/or implementing ocean climate innovations reveal three prevalent discourses: 'science outside society', 'science for society', and 'science with society'. One extreme, 'science outside society', emphasizes protection of scientific autonomy and freedom above all else. The other extreme, 'science with society', is premised on a moral duty to ensure socially created, just and desirable futures. We find these views about responsibility shape how scientists articulate the relationship between science and public good; expectations about the function of regulatory systems; the extent societal risks and benefits are accounted for; how scientific problems are characterised; the role and space for public participation; and the relationship between research and application. Such discursive variance within a small and tightly networked scientific community highlights clear moral and ethical tensions and underscores multiple urgent challenges for science to ensure responsible innovation and ocean futures. These challenges include: (1) reconciling views of responsibility in ocean science and innovation; (2) holding scientists and innovation proponents accountable for the futures they create; and (3) meeting the goals of sustainable and equitable ocean futures. Addressing these challenges is necessary to move towards 'a common measure of success' as set out under the UN Ocean Decade's vision for 2030, for which deliberations have already commenced[1]. We now discuss each of these challenges in turn.

Table 3 | Features of the 'Ocean science with society' discourse as represented by differential views of proponents and critics

	Discourse proponent		Discourse feature	Discourse critic	
	Illustrative quote	**View**		**View**	**Illustrative quote**
A.	*"[This involves] better consultation with Traditional Owners, better communication, better collaboration. We need to use a broad brains trust"* (regrowing targeted coastal species).	Science should be a socially responsive, future-oriented, collective pursuit of societal good and integrate diverse knowledge systems and values. Science should be conducted in conversation with, and/or co-produced with society.	**Role of science**	Difficult to implement socially responsive science as systems of funding do not allow or value such an approach. Scientific innovations may not facilitate sustained social benefits.	*"The system of funding doesn't allow such work [referring to social risk and impact assessments] to be done well prior to receiving funding"* (natural stabilisation of reefs and coasts).
B.	*"The scientific and conservation communities are trying very hard to develop codes of conduct that cover ethical research"* (ocean alkalinity enhancement).	Acknowledges limitations of regulation to adequately account for technological, ecological, and social implications. Instead, focuses on establishing internal institutional safeguards (e.g., Indigenous engagement protocols, local needs assessments).	**Role of regulation**	Ambiguity as to who is responsible for ensuring and enforcing social safeguards. Willingness of institutions to develop and maintain social safeguards is debated.	*"Who is responsible for permitting and maintaining the [regulatory] structures through time?"* (artificial habitat manipulation).
C.	*"[Engagement should involve] growing traditional researcher capacities using traditional processes and cultural observations"* (regrowing targeted underwater species).	Social risk is understood via engagement of local stakeholders, including First Nations groups. There is a need for more power to affected communities (i.e., via deliberative forums and capacity exchange).	**Approach to social uncertainty and risk**	Science and innovation are lacking expertise and guidance to be socially informed. Unaware of and/or unable to access independent social and ethical assessments.	*"Who are the stakeholders/affected peoples for open ocean spaces? There's a lack of certainty of who to consult if a consultative process were put in place"* (ocean alkalinity enhancement).
D.	*"An Indigenous research division [is needed that is] transdisciplinary and funded beyond the short term and does not use Western interpretations of success as quantitative measures"* (regrowing targeted underwater species).	Problems should be informed by diverse knowledges and views, and have transparent motives, values, and problem formulation. There is a propensity to develop long-term scalable solutions addressing root causes.	**Scientific approach to problem characterisation**	There is difficulty in expanding and embracing diverse worldviews, and challenges in generating cohesion for desired futures.	*"[There is] still not enough Traditional knowledge representation. Art, performance, and song are yet to be incorporated in scientific canons of understanding knowledges…"* (regrowing targeted underwater species).
E.	*"[There is a need for] more obvious engagement with, and contributions from, First Nations groups, to have more ownership and carriage of [innovation] proposals"* (artificial habitat manipulation).	Science and innovation should be co-designed with societal actors, and/or locally led to anticipate and respond to socially desirable and just futures.	**Role of public**	Public involvement can mean consideration for social implications becomes moral labour that is deferred onto local groups.	*"Often the work is done by community groups"* (regrowing targeted coastal species).
F.	*"[It is important] to progress at a pace appropriate to stakeholder, public and TO [Traditional Owner] capacity to engage, learn, and collaborate"* (regrowing targeted underwater species).	The public should be connected at research conception, deployment, and beyond. Slow and careful implementation to ensure collaboration and capacity exchange is needed.	**Relationship between research and application**	Capacity exchange processes are unclear, costly and progress too slowly due to deep engagement processes and monitoring of impacts.	*"Is there capacity on the ground to carry out these new ventures and how much would it cost to get our locals the capacity to run it?"* (regrowing targeted underwater species).

Challenge 1. Reconciling views of responsibility in ocean science and innovation

Any category of ocean innovation will inadvertently lead to modifications in social systems[31–33]. Therefore, consideration of how different stakeholders view the relationship between science and society is critical to fostering socially responsible scientific process and impacts[26]. The diversity of the 77,000 individuals—including scientists, governments, business and industry, philanthropic organisations and UN agencies from 4000 institutions—who are part of the UN Ocean Decade highlights the challenge of reconciling views of responsibility in ocean science and innovation[34]. In our study, we found the 'science outside society' discourse was portrayed as detached from societal goals and needs, and accountability to society. Here, scientists and scientific practice were positioned as politically neutral and objective (see also[20,27]). There was limited consideration and articulation of societal implications and scientific contributions were restricted to narrow audiences, methods, and metrics. At the other extreme, the 'science with society' discourse emphasised the moral obligations of scientists to contribute toward socially sustainable and just futures. Although largely aspirational, this discourse offered an alternative vision of the future that accounted for the dynamic relations between scientific innovation and societal good, emphasizing long-term benefits for society (see also[19,26,28,30]). These extremity views highlight the vastly different relationships possible between ocean science, innovation, and society, and clear tensions amongst scientific visions for responsible ocean futures.

Such disparate views of responsibility present challenges for generating a collective and shared set of principles or standards to ensure sustained benefits (and avoidance of harms) for oceans and ocean dependent people. Some scientists, for example, self-identify as 'de facto governors'[35] and 'makers of knowledge'[32] when it comes to problem and solution identification in experimental marine climate innovations. In doing so, they acknowledge that they wield power by swaying how, where, and by whom science is undertaken[36,37], including by controlling the generation of scientific information and how data is accessed[15,38,39]. However, given that science is not value-neutral or objective[16,40], and ocean climate innovations are rapidly evolving, articulating implicit values and working towards generating agreement on what responsible ocean science and innovation entails is still lacking. Assisted evolution of marine species (i.e., the genetic manipulation of wild organisms), for example, continues to raise complex and unresolved ethical questions about the shifting role of humans from being 'protectors' of nature to 'designers or engineers' of natural systems[2].

Different agendas and incentives can also present challenges for reconciling views of responsibility. We found in the 'science for society' discourse the delivery of science was perceived to be of public value, yet powerful interests still had a hand in shaping the scope and direction of innovations (i.e., privileging wealth and job creation). In fact, we found instances where scientific problems were constructed to serve certain solutions (i.e., those that prioritised technological, ecological, and economic outcomes), coerced by political agendas, and driven by external incentives, including to bring financial return on investment. Marine social scientists warn that as oceans are increasingly viewed as a lucrative economic frontier, economic motives are overriding consideration for social risks and benefits[41,42]. This concern is consistent with our findings, whereby both 'science outside society' and 'science for society' critics argued that neoliberal incentives mask and/or outweigh responsibilities to ensure socially just futures. The differing relationships with society, political agendas and external incentives raise serious questions about generating shared responsibility and accountability measures, particularly given the ethical and moral questions about whose interest ocean innovation stands to serve.

Challenge 2. Holding scientists and innovation proponents accountable for the futures they create

Mounting evidence suggests rapid and unchecked ocean innovation could cause substantial ecological and social risks for more than three billion ocean-dependent people[19,22,42]. Yet, our findings indicated mixed views on the role of regulatory and institutional measures for responsible ocean science and innovation. The 'science outside society' respondents asserted that scientists needed autonomy and freedom to generate knowledge (see also[27]), perceiving regulatory and permitting requirements as a barrier to ocean innovation. Calls for 'greater scientific freedom' is not wrong or necessarily unjust, particular in cases where governments and corporations have vested interests in supressing scientific discoveries (e.g., in ref. 43). The problem arises when calls for scientific objectivity and autonomy are wielded to frame science as noble 'solution-provider', granting scientists considerable freedom from political accountability and moral and social responsibilities[21].

In contrast, the 'science for society' discourse proponents perceived the principal role of regulations to be the provision of responsible safeguards, arguing that greater controls would ensure responsible science and development of novel ocean innovations. However, critics suggested there is an over-reliance on regulatory and institutional mechanisms ill-equipped to ensure responsible ocean science and innovation. Compounding this issue is a tendency for institutional ethical oversight to lack formal and/or systematic processes to account for public stakeholders needs, visions, and broader impacts on culture and society[44]. The consequence is that scientists and practitioners can become incentivised to consider poorly-designed regulation as an externally presented bureaucratic hurdle, nuisance, or box-ticking exercise that has to be overcome, rather than deeply engaging with, internalizing and embedding responsible innovation within their own practices[20]. This withdrawal of responsibility becomes particularly problematic when ocean-dependent peoples bear the brunt of ill-conceived impacts. For example, scientific research has in the past brought much harm to Indigenous Peoples, and scientists continue to downplay their responsibilities to uphold Indigenous rights, despite Indigenous Peoples being among the most affected social groups of both climate change and climate intervention[45,46]. This harm risks being reinforced by the prioritisation of Western and technocratic research framings, perpetuating ongoing colonial legacies that "marginalize, misrepresent, or silence Indigenous voices and perspectives"[45].

Results also confirmed a tendency for the viability of ocean innovations to be based on technological readiness and ecological feasibility more so than on societal risks or benefits. Technocratic worldviews, with strong footholds in the biosciences, tend to emphasise technical and ecological feasibility[47], with limited consideration for societal risks and benefits[5,18]. Ocean-based bio- and geo-engineering innovations in particular are inherently technocratic, prioritising technical and scientific interventions that perpetuate the extraction of services from nature over social-ecological care[31,47,48]. Technocratic frames can position societal applications, uses, and implications outside the mandates of scientists and innovation funders[24]. Instead, such societal considerations are treated as a moral load that can be abrogated or delegated to others (i.e., national governments, local communities)[49]. Using technical feasibility as a principal guiding metric can also lock in a unidirectional and one-dimensional view of innovation. Unidirectional, because technical and feasibility readiness are temporary milestones to be overcome on the path towards the ultimate goal: application. One-dimensional, because these assessments focus only on 'what can be done', not on 'why should it be done', 'whether it should be done at all', 'who is affected', or 'who is responsible'. Such assessments downplay the societal contributions of ocean innovations, and minimise the accountability of scientific agents to take responsibility for the futures they create[50].

Challenge 3. Meeting the goals of sustainable and equitable ocean futures

The United Nations Decade of Ocean Science for Sustainable Development (2021-2030) outlines goals for equitable and sustainable ocean futures in support of all the 17 Sustainable Development Goals of the 2030 Agenda[1]. Equity, inclusiveness, respect, and scientific integrity are core principles of the Ocean Decade[1], endorsed within the 'Ocean Voices: Advancing Equity Though the UN Ocean Decade' programme[51]. In practice, the Ocean Decade is focused on delivering ocean science and ocean solutions that focus on 'the science we *need*' and advancing understanding of the problems facing ocean dependent people, including "the barriers and enabling conditions for equity, fairness and justice"[1,51]. Yet, our results indicate stark differences in notions about how ocean science and innovation should responsibly interact with societal goals and needs. These findings raise significant concerns about the likelihood of fulfilling or progressing toward high-level commitments such as the UN Ocean Decade and the Sustainable Development Goals.

In both the 'science outside society' and 'science for society' discourses, we found a tendency for respondents to support the unidirectional 'delivery' of ocean science and innovation to society, whereby engagement entailed the public being informed or consulted at best. We also found the direction of communication occurring between science and society tended to be one-way; whereby science speaks to society, yet society is not granted the space to communicate back to science (see also[29]). Such prevalence of one-way scientific communication has been documented in the fields of genetically modified foods, solar-engineering and nuclear energy, where there are direct societal implications, yet experimentation is often shielded from the public[25,52]. This pattern is concerning as ocean science is already typically concentrated in Western, advanced economies[39], indicating a global imbalance in the production and flow of scientific knowledge from the West toward those in developing economies. Interdisciplinary scientists warn that if public engagement is viewed as peripheral or optional, innovations may perpetuate colonialism and ecological imperialism whereby Western scientists or conservationists impose extrinsic environmental goals, strategies and imagined solutions and futures on less powerful groups, for example First Nations Peoples and local communities[45,53].

Of all three discourses, the 'science with society' discourse of responsibility is likely best positioned to meet the UN Ocean Decade goals, and equitable and sustainable ocean futures more broadly. This discourse emphasises the moral and ethical obligations of scientists to contribute toward socially sustainable and just futures, founded on the principle that science should draw on diverse knowledge systems and values through co-construction with societal actors (see also[26]). Platforms such as the UN Ocean Decade provide a forum to garner attention and international momentum to ensure socially sustainable and just futures. Specifically, under the Ocean Decade's convening framework, there are opportunities for providing strategic guidance on the implementation of key actions to reconcile divergent views of scientific responsibility, challenge climate coloniality, and enable greater accountability. Despite such aspirations, our study findings suggested there are several barriers to enacting such a discourse, which pertain to time, commitment, resources, and expertise. As such, scientists and innovation proponents intervening in oceans need to enable the marine social sciences to play a larger role in understanding trade-offs, competing values, inequities and conflicts that may currently hamper socially responsible practice[15,54]. Likewise, social scientists have a responsibility to be leading voices and wade into this debate[15].

We also acknowledge that notions of responsibility are not always as neatly bounded as presented in this study. For example, one could advocate for greater scientific autonomy and freedom to trial novel techniques, yet still desire to deliver science that addresses complex social problems. In addition, our spectrum of scientific responsibility positions citizen co-production as the end goal, a premise that can overlook the role of context and politics[55]. Given that climate change is a wicked problem, addressing social learning of the wider community ('science for society'), rather than increasing power held by individual citizens ('science with society') may be more warranted, at least in the short-term. Even with these caveats, the articulation of these discourses provides an important first step and basis for understanding the different logics of responsibility, and the implications of such views. A failure to query such logics of responsibility may enable current popular innovations to crowd out alternative and socially innovative approaches[25,56], risking technological lock-in, and path dependencies[33,57], and further departure from sustainable and equitable futures. Understanding these foundations of responsibility can serve as a pre-cursor and set of principles to the realisation of an alternative vision of what responsible ocean science and innovation can entail. Established responsible innovation frameworks from the field of science and technology studies offer four broad dimensions and criteria to aid the realization of an alternative visions of responsibility in ocean science[17,44,58,59]. The dimensions include 'anticipation' (the level of foresight given to both the intended and potentially unintended social impacts), 'inclusion' (the accessibility and inclusiveness of public and stakeholder deliberation), 'reflexivity' (institutional responsibility and competency to interrogate societal implications), and 'responsiveness' (the presence and effectiveness of governance mechanisms to account for and manage societal implications). However, further applied research exploring how these four dimensions of responsibility could be used to develop marine-specific criteria for ensuring responsible ocean innovation are warranted.

Outlook for scientific responsibility in global ocean futures

Ocean science and innovation have the power to shape our shared future. However, ocean science and innovation itself does not lead to sustainable or unsustainable, just or unjust outcomes; these outcomes rest on enactments of responsibility based on implicit worldviews that shape scientific agendas, and how science is designed, funded, practiced and regulated[19]. In articulating these implicit yet divergent discourses of responsibility, we have better positioned ocean scientists and innovators to understand, question and improve their own standards of responsibility. Specific areas urgently requiring deeper reflection and enquiry include the purpose, motivations, and agendas of intervening in climate-impacted oceans. Such reflection and enquiry is dependent upon explicitly considering the motivations of vested interests, the depth and range of deliberation opportunities, the extent that diverse perspectives and worldviews are integrated into science and innovation, and the connection to broader societal goals[18,19,56]. Urgent and fundamental research questions for both biophysical and social marine scientists include: does ocean science and innovation respond to the needs of ocean-dependent people, and is it meeting those needs? Have anticipated implications for the well-being of these people been considered? Whose interest is ocean science and innovation serving? Do political and financial incentives undermine science outcomes that are of public value and good? Are adequate regulatory or institutional social safeguards in place? If there is limited room to anticipate and explore social implications and benefits of innovations, who then is accountable for the futures ocean innovations create? And are there more socially innovative alternatives that are being crowded out by current approaches?

Connecting responsibility discourses to scientific motivations, agendas, funding, and power could be a critical pathway to building scientific transparency, accountability, and benefit to ocean systems and global society. As we have suggested, existing responsible innovation frameworks (i.e.,[17,44,58,59]) could be a useful starting point in developing shared visions of what responsible ocean science and innovation may ultimately entail. Platforms such as the UN Ocean Decade provide a potential forum for the development of such shared understandings. Without this understanding, ocean science and innovation may inadvertently undermine sustainable and equitable development, and disproportionately impact ocean-dependent people and societies. The divergent discourses of responsibility revealed in this study present a fundamental and potentially incendiary moral and ethical quandary in ocean science. Ultimately, it is a question of which value-based interpretation of science takes priority: science as autonomous entity; science as noble provider of solutions; or science as a tool to work alongside society to fulfill humanity's needs. If the goal is to build more sustainable and just futures for oceans and people, ocean science requires a transformation in current approaches to responsibility to embrace an alternate vision—one that better accounts for the dynamic relations between ocean science and societal good.

Methods

Between October 2022 and March 2023, we conducted an anonymous, online, global survey of scientists and practitioners engaged in innovations currently being tested, implemented, or proposed globally to boost the resilience of marine systems to global heating. The survey instrument was created using Qualtrics, an online survey platform, and delivered via survey software provider SurveyMonkey. Our survey recruitment strategy primed for those with knowledge of 'new and emerging' ocean climate innovations, such as assisted evolution of species and cloud brightening. Recruitment first included purposive web sampling of the programs, funding schemes, and listed activities of global organisations and networks proposing, trialling and/or implementing ocean climate innovations. Invitation emails were distributed to leading actors in these organisations and networks via contact details publicly obtained. We then undertook a second round of targeted recruitment, where we invited participants from regions underrepresented in the sample, including participants associated with technologies or institution types not yet captured. The final round of recruitment included open sharing of the survey on social media platforms.

To ensure broad geographical coverage of respondents and innovations, the survey was produced in six languages, including English (EN) (82.8%, $n = 203$), Chinese (ZH-S) (4.9%, $n = 12$), Japanese (JA) (4.1%, $n = 10$), French (FR) (3.7%, $n = 9$), Spanish (ES-ES) (2.5%, $n = 6$), and Portuguese (PT) (2.0%, $n = 5$). A team of translators with marine science expertise translated non-English responses into English. Informed consent was obtained from respondents prior to commencing the survey. At the start of the survey, we provided a set of screening questions to ensure respondents were either scientists or practitioners who were engaged in marine innovation(s) which has/have been proposed, tested, or implemented globally to increase the resilience of oceans and marine systems to global heating. We excluded those aged 17 years or younger; and those who were unfamiliar with a specific ocean climate innovation.

Our final study sample was 243 respondents. Our survey sample was non-statistical as target respondents were a specialist group. Although we refer to respondents as 'scientists and practitioners', they identified as researchers (54%, $n = 132$), practitioners (agency employees, consultants, not-for-profit representatives) (35%, $n = 86$), community representatives (Traditional Owners or First Nations persons, artists, journalists, activists, teachers and students) (10%, $n = 25$) or donors (1%, $n = 2$). Nearly all respondents (91%, $n = 224$) were familiar with a specific ocean climate innovation for at least one year, with 44% ($n = 107$) reporting familiarity spanning 1–5 years; 27% ($n = 65$) spanning 5–10 years; 21% ($n = 52$) spanning 10 or more years; and 9% ($n = 21$) spanning less than 1 year. The innovations discussed by survey respondents were distributed across 10 geographic regions: Australia (tropical) ($n = 48$), Australia and New Zealand (temperate) ($n = 46$), North Pacific ($n = 46$), Caribbean ($n = 31$), North Atlantic ($n = 22$), Indian Ocean (12), Mediterranean ($n = 11$), South Pacific ($n = 7$), South Atlantic ($n = 3$), Red Sea ($n = 1$), and 22 were described as 'global'.

Discourse identification

A discourse is an ensemble of ideas, concepts and value-propositions through which meaning is produced[60]. Our discourse analysis traced for similarities and variance in how notions of responsibility were presented in survey responses. The three emergent discourses of responsibility were determined based on generally accepted principles from diverse areas of scholarship including responsible public research and policy[17,24,26,59]; ecology and/or biology ethics[2,20,27,28]; philosophy[21,29]; and science and technology studies[16,30].

Survey questions included multiple-choice with expanded response options, and open-ended question formats. We examined data from survey questions that elicited descriptive responses indicating where notions of responsibility were present. We then thematically grouped these qualitative descriptions based on normative dimensions of responsibility, using both inductive (survey data driven) and deductive (literature driven) reasoning. These included the role of science; the role of regulation; approach to social uncertainty and risk; approach to problem characterisation; role of public; relationship between research and application (defined in Box 1). We then organised these normative dimensions into three distinct discourses by adapting and expanding upon discourses of responsibility proposed by others (i.e.,[17,24–27,30,61]). We coded responses to identify support and critique for each discourse. We also acknowledge that discourses of responsibility contain broader elements than we examine. However, we reduced the elements explicitly to those our data confirmed. Examples of those we excluded were 'approach to ethics', 'governing experiments' or 'expectations of experimental systems' (see[25]). Hence, there is opportunity for future research to explore a more expansive range of responsibility elements from this data, and we encourage future researchers to do so.

Data availability

The dataset used and analysed in this study is available from the corresponding author on reasonable request.

Received: 13 May 2024; Accepted: 18 September 2024;
Published online: 29 September 2024

References

1. UNESCO-IOC. *The United Nations Decade of Ocean Science for Sustainable Development (2021-2030) Implementation Plan (No. 20)*. (UNESCO, 2021).
2. Filbee-Dexter, K. & Smajdor, A. Ethics of assisted evolution in marine conservation. *Front. Mar. Sci.* **6**, 20 (2019).
3. Low, S. & Buck, H. J. The practice of responsible research and innovation in "climate engineering". *Wiley Interdiscip. Rev. Clim. Change* **11**, e644 (2020).
4. Morrison, T. H. et al. Save reefs to rescue all ecosystems. *Nature* **573**, 333–336 (2019).
5. Gattuso, J.-P. et al. Ocean solutions to address climate change and its effects on marine ecosystems. *Front. Marine Sci.* 337 (2018).
6. Boettcher, M. et al. Navigating potential hype and opportunity in governing marine carbon removal. *Front. Clim.* **3**, 664456 (2021).
7. Powell, E. J., Tyrrell, M. C., Milliken, A., Tirpak, J. M. & Staudinger, M. D. A review of coastal management approaches to support the integration of ecological and human community planning for climate change. *J. Coast. Conserv.* **23**, 1–18 (2019).
8. Lubchenco, J. & Haugan, P. M. *The Ocean as a Solution to Climate Change: Five Opportunities for Action* In *The Blue Compendium: From Knowledge to Action for a Sustainable Ocean Economy* 619–680 (Springer, 2023).
9. Guerreiro, J., Calado, H. M., Bonnin, M., van Tatenhove, J. & Santos, C. F. New frontiers of marine governance in the ocean decade. *Front. Mar. Sci.* **10**, 1–3 (2023).
10. Jones, N. A., Shaw, S., Ross, H., Witt, K. & Pinner, B. The study of human values in understanding and managing social-ecological systems. *Ecol. Soc.* **21** (2016).
11. Rudd, M. A. Scientists' framing of the ocean science–policy interface. *Glob. Environ. Change* **33**, 44–60 (2015).
12. Mace, G. Whose conservation? Changes in the perception and goals of nature conservation require a solid scientific basis. *Science* **345**, 1558–1560 (2014).
13. Moon, K., Cvitanovic, C., Blackman, D. A. & Scales, I. R. Five questions to understand epistemology and its influence on integrative marine research. *Front. Mar. Sci.* **8**, 173 (2021).
14. Lau, J. D. et al. Morals and climate decision-making: insights from social and behavioural sciences. *Curr. Opin. Environ. Sustainability* **52**, 27–35 (2021).
15. Vadrot, A. B. et al. Towards a reflexive, policy-relevant and engaged ocean science for the UN decade: a social science research agenda. *Earth Syst. Gov.* **14**, 100150 (2022).
16. Latour, B. *Science in action: How to follow scientists and engineers through society*. (Harvard University Press, 1987).
17. Owen, R., Macnaghten, P. & Stilgoe, J. Responsible research and innovation: From science in society to science for society, with society. *Sci. Public Policy*, 751–760 (2012).
18. Ota, Y. et al. Finding logic models for sustainable marine development that deliver on social equity. *PLoS Biol.* **20**, e3001841 (2022).

19. Singh, G. G. et al. Will understanding the ocean lead to "the ocean we want"? *Proc. Natl Acad. Sci.* **118**, e2100205118 (2021).
20. Wolpe, P. R. Reasons scientists avoid thinking about ethics. *Cell* **125**, 1023–1025 (2006).
21. Douglas, H. E. The moral responsibilities of scientists (tensions between autonomy and responsibility). *Am. Philos. Q.* **40**, 59–68 (2003).
22. Low, S., Baum, C. M. & Sovacool, B. K. Taking it outside: exploring social opposition to 21 early-stage experiments in radical climate interventions. *Energy Res. Soc. Sci.* **90**, 102594 (2022).
23. Hughes, T. P., Baird, A. H., Morrison, T. H. & Torda, G. Principles for coral reef restoration in the anthropocene. *One Earth* (2023).
24. Mitcham, C. Co-responsibility for research integrity. *Sci. Eng. ethics* **9**, 273–290 (2003).
25. Stilgoe, J. Geoengineering as collective experimentation. *Sci. Eng. Ethics* **22**, 851–869 (2016).
26. Glerup, C. & Horst, M. Mapping 'social responsibility'in science. *J. Responsible Innov.* **1**, 31–50 (2014).
27. Bradshaw, G. A. & Bekoff, M. Ecology and social responsibility: the re-embodiment of science. *Trends Ecol. Evol.* **16**, 460–465 (2001).
28. Sandler, R. The ethics of genetic engineering and gene drives in conservation. *Conserv. Biol.* **34**, 378–385 (2020).
29. Elam, M. & Bertilsson, M. Consuming, engaging and confronting science: The emerging dimensions of scientific citizenship. *Eur. J. Soc. Theory* **6**, 233–251 (2003).
30. Åm, H., Solbu, G. & Sørensen, K. H. The imagined scientist of science governance. *Soc. Stud. Sci.* **51**, 277–297 (2021).
31. Cooley, S. R., Klinsky, S., Morrow, D. R. & Satterfield, T. Sociotechnical considerations about ocean carbon dioxide removal. *Annu. Rev. Mar. Sci.* **15**, 41–66 (2023).
32. Möller, I. *The Emergence of Geoengineering: How Knowledge Networks Form Governance Objects*. (Cambridge University Press, 2023).
33. Morrison, T. H., Barnett, J., Gurney, G. G., Lau, J., Barnes, M. L., Cinner, J., Hettiarachchi, M. & Cohen, P. Overcoming lock-in of science-policy responses to reef heating. *Marine Policy,* 170, 106380 (2024).
34. UNESCO-IOC. *Ocean Decade Progress Report 2022–2023.* (The Ocean Decade Series, 46). (Paris, 2023).
35. Schadeberg, A., Kraan, M., Groeneveld, R., Trilling, D. & Bush, S. Science governs the future of the mesopelagic zone. *npj Ocean Sustain.* **2**, 2 (2023).
36. Stefanoudis, P. V. et al. Turning the tide of parachute science. *Curr. Biol.* **31**, R184–R185 (2021).
37. Shellock, R. J. et al. Breaking down barriers: the identification of actions to promote gender equality in interdisciplinary marine research institutions. *One Earth* **5**, 687–708 (2022).
38. Blasiak, R., Jouffray, J.-B., Wabnitz, C. C. & Österblom, H. Scientists should disclose origin in marine gene patents. *Trends Ecol. Evol.* **34**, 392–395 (2019).
39. Tolochko, P. & Vadrot, A. B. The usual suspects? Distribution of collaboration capital in marine biodiversity research. *Mar. Policy* **124**, 104318 (2021).
40. Jasanoff, S. Science and technology studies. *Research Handbook on Climate Governance. Cheltenham, UK: Edward Elgar Publishing*, 36-48 (2015).
41. Silver, J. J., Gray, N. J., Campbell, L. M., Fairbanks, L. W. & Gruby, R. L. Blue Economy and Competing Discourses in International Oceans Governance. *J. Environ. Dev.* **24**, 135–160 (2015).
42. Bennett, N. J., Blythe, J., White, C. S. & Campero, C. Blue growth and blue justice: Ten risks and solutions for the ocean economy. *Mar. Policy* **125**, 104387 (2021).
43. Laurance, W. F., Mudhoffir, A. M., Pusparini, W., Meijaard, E. & Engert, J. E. In Indonesia and beyond nature conservation needs independent science. *Curr. Biol.* **33**, R706–R707 (2023).
44. Owen, R. & Pansera, M. *Responsible Innovation and Responsible Research and Innovation.* In *Handbook on Science and Public Policy* (Eds. Dagmar Simon, Stefan Kuhlmann, Julia Stamm, Weert Canzler) 26-48 (Edward Elgar publishing, 2019).
45. Ignace, L. et al. Researchers' responsibility to uphold Indigenous rights. *Science* **381**, 129–131 (2023).
46. Pradhan, S. K., Cohen, P. J., Lawless, S. & Dean Fitz, K. *Pathways toward Equitable Climate Resilience, Sustainable Fisheries & Tenure Security; A Brief for Funders,* (Zenodo, 2024). https://doi.org/10.5281/zenodo.12787752.
47. Streit, R. P., Morrison, T. H. & Bellwood, D. R. Coral reefs deserve evidence-based management not heroic interference. *Nature Climate Change*, 1–3 (2024).
48. Bayraktarov, E. et al. Motivations, success, and cost of coral reef restoration. *Restor. Ecol.* **27**, 981–991 (2019).
49. Lawless, S., Song, A. M., Cohen, P. J. & Morrison, T. H. Rights, equity and justice: A diagnostic for social meta-norm diffusion in environmental governance. *Earth Syst. Governance* **6**, https://doi.org/10.1016/j.esg.2020.100052 (2020).
50. Groves, C. Technological futures and non-reciprocal responsibility. *Int. J. Humanit.* **4**, 57–61 (2006).
51. Nippon Foundation. *Ocean Voices: Advancing equity through the Decade: Decade Programme*, https://oceannexus.uw.edu/wp-content/uploads/sites/33/2021/11/16_Ocean-Voices_Factsheet.pdf (2021).
52. Glover, D. *Public participation, accountability and the stewardship of transgenic crops* In *Governing Agricultural Sustainability* 167-173 (Routledge, 2015).
53. Sultana, F. The unbearable heaviness of climate coloniality. *Political Geography* **99**, https://doi.org/10.1016/j.polgeo.2022.102638 (2022).
54. Castree, N. et al. Changing the intellectual climate. *Nat. Clim. change* **4**, 763–768 (2014).
55. Murunga, M., Macleod, C. & Pecl, G. Assumptions and contradictions shape public engagement on climate change. *Nat. Clim. Change*, 1–8 (2024).
56. Partelow, S. et al. Five social science intervention areas for ocean sustainability initiatives. *npj Ocean Sustain.* **2**, 1–11 (2023).
57. Morrison, T. H. et al. Radical interventions for climate-impacted systems. *Nature Climate Change*, 1-7 (2022).
58. Macnaghten, P. *The making of responsible innovation*. (Cambridge University Press, 2020).
59. Stilgoe, J., Owen, R. & Macnaghten, P. Developing a framework for responsible innovation. *Res. Policy* **42**, 1568–1580 (2013).
60. Hajer, M. & Versteeg, W. A decade of discourse analysis of environmental politics: Achievements, challenges, perspectives. *J. Environ. Policy Plan.* **7**, 175–184 (2005).
61. Douglas, T. The dual-use problem, scientific isolationism and the division of moral labour. *Monash Bioeth. Rev.* **32**, 86–105 (2014).

Acknowledgements

We thank the many respondents who generously shared their time and experiences in the global survey from which this study draws. We thank Emily Ogier and Coco Knox for survey data preparation, and survey translators Sarah Kwong, Marion Angelini, Juliano Morias, Victor Huertas Martin, Masayuki Tatsumi, Hanaka Mera, and Colette Appert. We acknowledge Andrew Dart for revision support and Jerker Lokrantz for assistance with figures. We also thank the two anonymous reviewers for their feedback. This work was supported by the Australian Research Council (ARC) under funding received from the ARC Discovery Program DP220103921 (T.M.); The Nature Conservancy under funding received from the SNAPP program (T.M.); and the AIMS@JCU Research Fellowship (S.L.). This research was undertaken in accordance with James Cook University human research ethics approval (H8845).

Author contributions

Conceptualization: S.L., J.L., R.S., T.M.; Methodology & Investigation: S.L. & T.M.; Analysis: S.L.; Preparation - Original Draft: S.L., J.L., R.S., T.M.; Writing – Reviewing & Editing: S.L., J.L., R.S., T.M.; Funding Acquisition: T.M.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s44183-024-00086-2.

Correspondence and requests for materials should be addressed to Sarah Lawless.

Reprints and permissions information is available at http://www.nature.com/reprints

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.