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Food for Thought

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The future of ocean plastics: designing diverse collaboration frameworks

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This paper aims to guide the stakeholder engagement process related to plastic pollution research in marine environments. We draw on advice identified during an online workshop (Ocean Plastic Workshop 2022) organized by Early Career Ocean Professionals (ECOPs) from 11 countries, held in April 2022. International experts and workshop participants discussed their experiences in the collaborative development and implementation of ocean plastic pollution projects held worldwide, guided by three main questions: (i) What is the role of scientists in a multi-stakeholder project? (ii) How should scientists communicate with other stakeholders? (iii) Which stakeholders are missing in collaborative projects, and why are they missing? This multidisciplinary, co-learning approach highlights the value of stakeholder engagement for ocean plastic projects with an end goal to identify and implement ocean plastic solutions via innovative technologies, informing policy, community engagement, or a combination of all three approaches. The target outcomes of the workshop described in this paper include the identification of transdisciplinary (academic-stakeholder) engagement frameworks and specific suggestions that can serve as guidelines for the development of future plastic pollution projects.

Keywords: communication, marine litter, plastic pollution, policy, research, stakeholders, technology.

Introduction

As the largest ecosystem on our planet, the ocean sustains life on earth and provides our civilization with key ecosystem services, including climate regulation via the transport of heat, food provision, and biogeochemical cycling of nutrients (Sala *et al.*, 2021; Naselli-Flores and Padisák, 2022). However, in recent decades, the ocean has been increasingly impacted by human-induced global stressors, including climate change, population growth, and plastic pollution (Sandifer and Sutton-Grier, 2014). The quality and resilience of ocean ecosystems are in peril from increased anthropogenic threats, of which plastic pollution is one of the most tangible. Annually, between 19 and 23 million metric tonnes of plastic waste are deposited in aquatic environments, and if emissions are not curbed, this amount is estimated to reach ∼53 million metric tonnes by 2030 (Borrelle *et al.*, 2020).

Plastic pollution is now identified as a planetary threat and a global ecological, social, and economic crisis posing

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significant risks to biodiversity, economies, and human health (Law, 2017; Villarrubia-Gómez *et al.*, 2018; MacLeod *et al.*, 2021; Bastyans *et al.*, 2022). This has prompted a global response to develop multiple national and international legislations. A significant milestone was the agreement of the United Nations Environment Programme (UNEP) on a mandate to negotiate a legally binding international treaty aimed at addressing the holistic impact of plastics (https://wedocs.unep.org/bitstream/handle/20.500.11822/39640/K2200733%20-%20UNEP-EA-5-RES-14%20-%20ADVANCE.pdf). This mandate called for a "Treaty to End Plastic Pollution by 2024", and concludes with a request to the UN Executive Director to create a forum that is open to all stakeholders for the exchange of information and activities related to plastic pollution. Three draft resolutions were brought forward by member states, with the joint draft resolution by Rwanda and Peru (https://wedocs.unep.org/bitstream/handle/20.500.11822/37395/UNEA5.2%20Global_Agreement_Explanatory%20note%20and%20Resolution%2027%20October.pdf) gaining the most support. The primary reasons being, on the one hand, the aim of establishing a legally binding instrument as opposed to a voluntary measure. On the other hand, the draft resolution is specifically setting out to combat marine, as well as previously unaddressed, but most significant land-based sources of plastic pollution (Wang, 2023). Furthermore, it supports the previously established general consensus that plastics need to be addressed along their entire life cycle, from extraction of raw materials to legacy plastic pollution, to allow for an equitable distribution of costs and benefits across the global value chain (Simon *et al.*, 2021).

Ocean health plays a vital role in the achievement of the United Nations (UN) 2030 Agenda for Sustainable Development, in particular through Sustainable Development Goal (SDG) 14: "Life below water" (https://sdgs.un.org/sites/default/files/2022-01/DESA-Oceans-VCs.pdf). The urgent need to apply ocean science to support an ecological transition has led to the UN proclaiming the Decade of Ocean Science for Sustainable Development (2021–2030; hereafter the UN Ocean Decade) (https://unesdoc.unesco.org/ark:/48223/pf0000381708.locale=en). The main objectives of the UN Ocean Decade are to produce inter- and trans-disciplinary science that provides a solution-driven understanding of the ocean ecosystems to stop ecological degradation and create the conditions to promote sustainable development. Seven interrelated Ocean Decade Outcomes have been defined under the vision and mission statements. Outcome 1 is a "Clean Ocean", with a goal to identify, reduce, or remove sources of pollution (https://www.oceandecade.org/vision-mission/).

The many sources of plastic pollution and the range of impacts plastics have across their lifecycle—from production to use and disposal—make tackling plastic pollution an extremely complex societal challenge (Vince and Hardesty, 2017). Conventional top–down (government-driven) approaches have only partially addressed similarly complex environmental issues before, such as, for instance, climate change and biodiversity loss (Iyer-Raniga and Treloar, 1999). Effective responses require decision-makers to navigate multiple dimensions (for example, scientific, political, economic, and cultural). It also requires scientists and industries to understand the extent of plastic pollution impact and co-develop innovative solutions, and for the general public to gain an understanding of the environmental impact of their actions to make sustainable behavioural changes (Cordier and Uehara, 2019; Lau *et al.*, 2020; Sandu *et al.*, 2022).

Sub-national responses to plastic pollution often include two strategies, also referred to as Honolulu strategies. These include legislative strategies (e.g. a complete ban of plastics) or market-based strategies (e.g. imposing levies on plastic bags). Germany, Denmark, and Kenya, for instance, have imposed plastic bans in their countries, while North America, Canada, and South Africa have imposed levies on plastic bags. Nations near coastal areas are especially under pressure to manage their plastic use as they tend to significantly impair ocean health through their large contribution of plastic debris into the ocean. India and China, for instance, have imposed plastic bans following reports that they are amongst the largest contributors of debris in the oceans (Xanthos and Walker, 2017; Schnurr *et al.*, 2018; Diana *et al.*, 2022). However, given the complexity of the ocean plastic pollution challenge, a transdisciplinary, collaborative approach that includes a diversity of voices (ocean stakeholders) is required to work together to understand and solve these issues (Clarke *et al.*, 2013; Röckmann *et al.*, 2015; Riechers *et al.*, 2021).

Stakeholder engagement in environmental management is a process by which stakeholders (i.e. those directly or indirectly affected by an issue and able to affect a decision) take active roles in collaborative research, planning, and/or actions impacting their lives (Lockwood *et al.*, 2010; Plummer *et al.*, 2017). The core challenge in realizing the transformative potential of stakeholder engagement is identifying the mechanisms through which it can lead to effective social and environmental change (Newig *et al.*, 2018; Eaton *et al.*, 2021). With respect to marine environmental issues, early career researchers have been recognized as key stakeholders by the UN Ocean Decade, which has endorsed the role of and the need for involving Early Career Ocean Professionals (ECOPs) in the decision-making process to encourage and support future ocean leaders to be engaged in the discussions, ensuring a sustainable ocean future (Kostianaia, 2022).

Within this context, we organized a workshop in April 2022 to provide a platform for multi-directional knowledge exchange between ECOPs, experienced ocean professionals (EOPs), and other stakeholders within and beyond academia working on ocean plastic pollution. The central theme guiding the discussions was how stakeholders can help shape future plastic pollution research and, in turn, how current ocean plastic research can inform solutions to ocean plastic pollution. Collaboration frameworks spanning the globe and linking professional disciplines can enable a more effective co-production of knowledge by ocean plastic researchers and multi-sectoral stakeholders (Buyana, 2020; de Salas *et al.*, 2022) to meaningfully address plastic pollution at local and global scales. The target outcomes of the workshop and aims of this paper include the identification of innovative and transdisciplinary (academic-stakeholder) engagement frameworks and research plans.

Methods

An open solicitation for ECOPs to join the workshop leadership team was posted to social media (Twitter) and sent to existing plastic pollution networks via email listservs and Slack groups, with a link to an online application form. In addition to background information, including geographic location, applicants were asked to submit a one-minute video describing their interest and motivation to join the project. Team leaders carefully reviewed the applications and selected the team based on qualifications and enthusiasm, while maximizing geographic and gender diversity. Selected ECOPs co-organized and co-hosted the Ocean Plastic Workshop in April 2022 held virtually via the Zoom© platform across three different time zones. The ECOPs consisted of PhD and postdoctoral researchers with expertise in physical oceanography, ecotoxicology, fisheries science, environmental chemistry, marine biology, ecology, and science policy related to ocean plastics, and originate from (in alphabetical order): Argentina, Australia, Belgium, Brazil, Ghana, Italy, Kenya, Malaysia, Norway, Portugal, South Africa, Tunisia, and USA.

The workshop ran over three days (5, 6, and 7 April) to cover three specific themes, namely: (1) Innovative technologies to monitor and mitigate ocean plastics; (2) Policies and actions for a plastic-free ocean; and (3) Public and community engagement related to ocean plastics. Prior to the event, a literature review of the successes and failures of past stakeholder engagement projects was conducted. ECOPs grouped themselves according to themes relating to their research interests or background. Relevant publications were shared and presented to the whole group during weekly meetings. Useful findings were collated to contribute to the introduction of this paper and to serve as a basis for structuring the discussion during the workshop.

The three-day Ocean Plastic Workshop (https://www.oceanplasticworkshop.com/) consisted of two sessions per day (morning and afternoon) that took place every day in three different time zones across the globe (from GMT+10 to GMT-7; 18 sessions in total). Panellists were selected and identified by ECOPs and invited according to their expertise in relation to the specific workshop themes. The organizers actively chose panellists spanning a range of career levels and stakeholder groups or sectors. The final list of invited panellists (Supplementary Table S1) was reviewed and approved by the whole group before sending out the invitations. For the purposes of this study, a stakeholder is defined as anyone who either produces plastics, benefits from or is affected by plastics, manages plastics at their end of life, or researches the movement and impacts of ocean plastics, i.e. waste pickers, recyclers, packaging producers, businesses, supply chain specialists, policy makers, NGOs, artists, media professionals, researchers, EOPs, and members of the public.

Three to five panellists were invited for each time zone and asked to join a morning session (Panel Discussion) and an afternoon session (Interactive Discussion) of 1.5 h each. In the Panel Discussion, the ECOP moderator asked three main questions to each panellist:

(1) What should be the role of scientists in a multi-stakeholder project?

(2) How can stakeholders best communicate with one another?

(3) Which stakeholders are missing in multi-stakeholder projects about plastic pollution solutions, why are they missing, and how should we engage them?

To recruit participants, workshop organizers created a graphic postcard and written announcement for the workshop that were distributed on social media (Twitter, Linkedin, Facebook, etc.) and through the existing networks of the organizing team via email listservs, Slack groups, and other means. The announcement included a registration link to the workshop website. More than 530 participants joined the discussions during the online workshop, with an average presence of ∼30 participants per session. The participants were encouraged to write their questions to the panellists using an interactive virtual whiteboard platform specifically designed for this workshop using the Miro© online tool (www.miro.com; an example of the layout we designed is provided in Supplementary Figure S1). Panellists answered questions verbally in the last 10 min of each session. In the afternoon interactive discussion, workshop participants were invited to actively participate as both stakeholders and experts. The same questions posed to the panellists during the morning panel discussion were asked to all the participants, to which they could respond using the designed Miro board. All communication and feedback were conducted using the English Language and real-time captioning was turned on to assist non-English speakers in following the conversation. To generate the results and discussion, the 18 session recordings were rewatched by their respective moderators, and the Miro board comments from participants and panellists, as well as the summaries from all session note-takers, were synthesized.

Results and discussion

The role of scientists in multi-stakeholder projects

Based on input received through the interactive whiteboard during our virtual event in April 2022, we present a suggested collaborative framework to guide scientists working in multi-stakeholder projects (Figure 1, Table 1). This framework is composed of comments from the participants who contributed to the discussions. The number of comments across all sessions were grouped into seven main ideas, which we have organized into a path followed throughout a multi-stakeholder project, from conception and idea development to research activities and finally dissemination. The size of each bubble shown in Figure 1 is representative of the number of comments supporting each role, and can be seen as a reflection of this community's understanding of how the scientist should contribute. This may correspond to the importance of any given task as well as how much time the scientist should be expected to commit to different contributions. This framework may help guide stakeholders in assigning responsibilities and tasks at the outset of a project.

From the workshop discussions, a consensus clearly emerged that the scientist's role is fundamentally connected to providing sound, evidence-based information, as well as reliable results and relevant data analysis to answer research questions (step 1 in Figure 1). In the context of ocean plastic pollution, natural scientists act primarily as knowledge brokers on subjects such as the fate and transport of plastic, the ecological impacts of plastics, and methods for monitoring, sampling, and analysing plastics. This role is tightly connected to academic expertise; however, communication skills are equally critical to ensure that other stakeholders acquire the correct and appropriate information (step 2 in Figure 1). From the workshop, it also emerged that input from stakeholders should be received before the scientists begin their research and that this is a crucial step to ensure an effective "co-creation of science" between scientists and other interested parties.

Lastly, it should be noted that the workshop was not only limited to discussing the role of natural scientists, but it also identified social, behavioural, legal, and humanities scientists as essential stakeholders whose involvement is crucial if effective solutions are to be achieved. Their participation emerged as one of the very clear strategies to help natural scientists integrate information on human and moral aspects, for

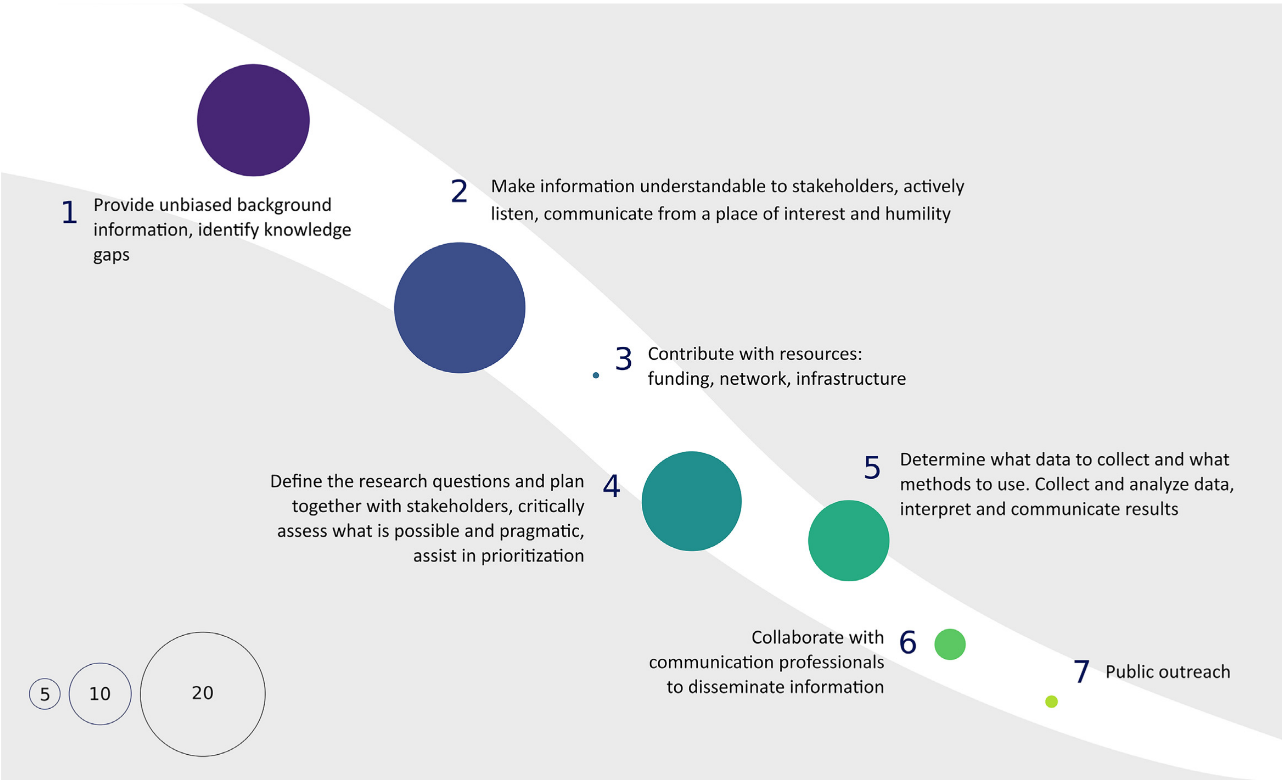

Figure 1. Role of the scientist in a multi-stakeholder project, ordered chronologically from project inception to completion. Bubble size indicates the number of comments made by workshop participants on all Miro discussion boards used in the workshop ($n = 9$), which articulated support for each statement.

example, regarding consumer behaviour, marketing strategies, or complex legal frameworks. Social science also offers a wide methodological range, which enriches scientific studies with new approaches and promotes public engagement.

Role of the scientist in innovative technological solutions

In the early stages of a project planning, the role of natural scientists is mainly focused on providing stakeholders with unbiased information about state-of-the-art technology in plastic pollution research. Technology plays a critical role in science and the provision of a cleaner ocean; however, it comes with its challenges. Throughout the workshop, we learned how technology is being used in diverse and strategic ways to monitor and tackle ocean plastic pollution. Examples range from artificial intelligence (AI) to classify beach litter, satellite and drone technology for remote sensing of ocean plastics, the development of new (automated) sampling techniques, and engineering solutions for plastic remediation at large scales.

Technology in this sphere is rapidly evolving, so providing expertise and context for research questions is critical to ensure effective use of resources and to avoid recreating data and duplicating efforts. In addition, plastic pollution research is generally suffering from a lack of standardization and harmonization with respect to methods for sampling and analysis (Stock *et al.*, 2020). Adhering to recommendations for quality standards and harmonization of data reporting requires near-constant evaluation of current scientific literature. Although there is still work to be done in academia to reach universal standardized practices, the role of scientists is to define robust, replicable methods for sampling ocean plastics and to advise other scientists, NGOs, citizens, and industry which aims to collect data, in order to avoid repeated efforts or using unreliable protocols and procedures.

Role of the scientist in policy-driven solutions

To be effective, policies and actions to solve ocean plastic pollution must be built on sound scientific data and evidence. In the policy space, scientists are typically regarded as trustworthy and reliable sources of unbiased information. Besides this essential role, during our workshop, we learned from our panellists that, given the transdisciplinary nature and diverse set of stakeholders within the marine policy-making arena, effective policy-driven ocean plastic solutions occur when scientists assume other important roles. These can include being a project manager, science communicator, policy advisor, and co-producer of knowledge together with other stakeholders (Iwamoto *et al.*, 2019). For example, scientists can organize and moderate dialogues with stakeholders to gain an understanding of problems and needs, and refine them to make sure they are scientifically testable or answerable. For example, to design the Strategic Plan to Monitor and Assess Marine Litter in Sao Paulo State (SPMAML) in Brazil, scientists held two workshops and four meetings to encourage stakeholders to share their experiences and local knowledge about marine litter in Sao Paulo State. This form of participatory construction promoted further data collection to inform and advise policy-makers in designing a more effective monitoring plan.

Another example underlines the role of social scientists specifically. Marks *et al.* (2023) undertook a qualitative study of Thailand's circular economy and concluded that structural and societal inequities and inequalities, particularly affecting

Table 1. A table summarizing the main outcomes of the Ocean Plastic Workshop 2022, organized by ECOPs in April 2022.

Theme	Framework step	Example
Role of scientist	Provide unbiased background information	Ensure transparency, consult all stakeholders from the initialization phase of the project.
	Make scientific information understandable to all stakeholders	Communicate clearly in simple language and facilitate translation of findings to local languages if required.
	Contribute with resources	Provide necessary resources to ensure success of the project. e.g. reading material, survey devices, methodology guidelines, etc.
	Define research questions and plan together with stakeholders, assist in prioritization	Take a "requirements engineering" approach and create simple, clear requirements, and translate them into concrete tasks.
	Determine data to collect and methods to use, collect, and analyse data	Choose sampling and analysis methods that adhere to recommendations for quality standards and harmonization of data reporting for micro- and macro-plastics.
	Collaborate with stakeholders via communication channels or professionals	Consult community leaders to guide communication with local community members.
	Public outreach	Collaborate with media professionals to promote awareness and identify community needs.
Communication	Establishing a communication style to ensure positive collaboration	Use online platforms (e.g. Miro) to facilitate easy (potentially anonymous) input from stakeholders. Hosting workshops that allow equitable input from all participants and embracing their expertise.
	Communication and dissemination of scientific results	Work with creative professionals, social media managers, or trained science communicators.
Involve missing stakeholders	Outreach to stakeholders using specific channels of communication	The Strategic Plan to Monitor and Assess Marine Litter in Sao Paulo State (SPMAML) in Brazil held two workshops and four meetings to encourage stakeholders to share their experiences and local knowledge about marine litter in Sao Paulo State.
	Integration of stakeholders through participation in research	Sourcing data from the general public through community science initiatives (i.e. citizen science).

International experts and workshop participants discussed their experiences in the collaborative development and implementation of ocean plastic pollution projects held worldwide, guided by three main questions: (i) What is the role of scientists in a multi-stakeholder project? (ii) How should scientists communicate with other stakeholders? (iii) Which stakeholders are missing in collaborative projects, and why are they missing?

the informal sector, are problems inherent to the circular economy model itself rather than being a nation-specific problem. They further outlined pathways to overcome these common inequalities and most importantly demonstrate that the need for the involvement of social scientists in designing the future of ocean plastics cannot be overstated, to ensure that equitable and just social and economic improvements are at the forefront, alongside environmental objectives. These findings may also be of relevance to the Rwandan/Peruvian draft resolution to the UNEP Treaty, which heavily features the role of circular economy approaches.

Science and policy are indeed complementary to tackle and solve complex societal issues, and cooperation between these two actors is fundamental to achieving meaningful results. From our workshop, clear needs that emerged included increased dialogue, trust, and understanding of requirements, as well as languages and diversity of inputs between scientists and policy-makers. There is a need to train a new generation of scientists able to effectively engage in policymaking. At the same time, the involvement of the general public and indigenous communities is also important for knowledge creation and sustainable policy production. The new EU mission "Restore our Ocean and Waters by 2030" will be an opportunity to implement such objectives. Following the launch of the Mission Charter, EU Member States, regions, and relevant stakeholders will further engage with actions for a successful implementation of the Mission and regional "lighthouses" to work collaboratively towards the goal of a clean ocean.

Role of the scientist in public engagement solutions

Scientific discoveries and innovations play a key role in societal development, and public engagement is emerging as a fundamental necessity of modern research projects. Successful public engagement strategies involve maintaining a productive two-way dialogue between scientists and members of the public where both groups learn from each other about developments in science and their applications to society. This includes: the problems that communities view as worth solving; the information society needs and wants from scientists; the potential risks, benefits, and consequences of new technologies; building and sustaining trust among stakeholders; and finding common ground to work towards shared decisions about science-related controversies (Borchelt and Hudson, 2008). Additionally, stakeholders and the general public need consistent and congruent information to oppose general scientific negationism and denialism (Neves *et al.*, 2022). The challenge for the future is for scientists to gain a better understanding of the public's needs and interests and to make public engagement strategies more effective. Making scientific information publicly available (e.g. via open access) and easily understandable to all interested parties remains important. Successful multi-stakeholder research projects that have societal impact typically consult interested stakeholders (e.g. potential funders, elected officials, donors, community leaders, advocacy organizations, NGOs, students, and other members of the general public) and involve them during all stages of the project (Heagerty, 2015). The overarching consensus from the workshop discussion regarding public outreach programmes was that, in order to make research projects more effective, a dialogue between community stakeholders and scientists as well as a much deeper inclusion of the society in the early phases of the scientific process (i.e. co-creation of science) is beneficial, particularly for the applied science disciplines.

Dissemination of scientific results to the general public is often ignored (Llorente *et al*., 2019), perhaps in part because most researchers do not receive specific scientific communication training (Brownell *et al*., 2013). Hence, scientists themselves may not be the most effective communicators, or translators, of science to a general audience. If so, scientists can bring creative professionals, social media managers, or trained science communicators to a project. Programmes dedicated to science communication in scientific institutions could serve to train people, including interested scientists, in communication skill sets such as multimedia, content creation, and art-science collaboration. At the same time, science dissemination training could be included by universities in academic curricula. Successful public engagement projects based on collaborations with science communicators require scientists to establish transparent, open communication channels with their collaborators to ensure that relevant language and scientific understanding are preserved while being jargon-free and easy to understand. Further, scientists should be ready to invest time and effort, apart from their research, to engage in dissemination activities. Academic institutions should support scientists with these endeavors by providing time and effort to disseminate research.

Communication between stakeholders

Though it is obvious that communication with stakeholders is essential, it is the quality of communication that often determines the success of a project. We asked participants when and how stakeholders are defined, and what specific strategies and principles govern good communication to build and maintain their trust and active engagement. It was agreed that communication methods should be tailored to each project and that no "one size fits all" solution exists. However, some overarching values and practices did emerge (Figure 2a). Openness, understanding, and inclusion were the most frequently described components of effective communication, while positive attitudes and respect towards others (including finding common ground when contrasting views arise) play a large role in how stakeholders communicate, which in turn affects the success of the project (Goodman and Sanders Thompson, 2017; Lavery, 2018; Shackleton *et al*., 2019).

Practices for good communication are often centred around the idea that different stakeholders "*speak different languages*". Ensuring that stakeholders can understand and participate in project development requires knowledge translation from all corners; that is, discussions should be less technical and more easily understood by everyone involved (Adam *et al*., 2020; Schmaltz *et al*., 2020). To facilitate achieving this common understanding, multi-stakeholder projects could engage the services of a third-party interpreter, such as a science communication specialist (as mentioned above), to help establish and maintain good communication between stakeholders. In cases where stakeholders in fact speak different languages or dialects, community partners with linguistic abilities or translation services should be considered, as well as the use of objects and storytelling (Ballard *et al*., 2021). Alternatively, one of the panellists advised: "*Do not find the interpreter, be the interpreter*", and as a matter of fact, many participants commented that scientists should seek out—or be provided with—training in soft skills (e.g. in project management) to be better prepared for collaborative projects.

Communication during technology-focused projects

To assist with both knowledge translation and communication of expectations and goals, one participant suggested the use of "requirements engineering", which is a standard tool in software engineering. In this method, initial stakeholder intentions do not serve as stakeholder requirements, since they often lack definition, analysis, possibly consistency, and feasibility (ISO, 2018). The process of formulating requirements in a standardized way helps transform general stakeholders' objectives into more concrete tasks (Stock *et al*., 2022). In the instance of ocean plastics, for example, a scientist may have the objective of remotely monitoring floating debris with drones. However, this intention must be translated into specific technical requirements for the engineers designing the monitoring tool. For example, what size of debris is being monitored? What area should be monitored and how often? This allows for a concrete response from the engineer on feasibility and technical limitations to address the desired objectives. From experience working with requirements engineering, one of the panellists stated that "*projects that have very well-defined requirements keep everyone aligned on the same path*", while advising that requirements should be as simple and clear as possible to maintain a basic, common understanding of the shared objectives.

Communication during policy-oriented projects

Scientists are encouraged to engage in the science-policy interface, and efficient frameworks exist to facilitate this (e.g. see Evans and Cvitanovic, 2018). Scientists may consider policy impacts as a critical final step in their research and identify which types of communication materials are most important to achieve their communication goals. Blogs, short articles, and social media can rapidly shape policy debates and remain a crucial source of information for many policy actors (Evans and Cvitanovic, 2018).

Still, a number of barriers exist in science-policy conversations, such as the fast-moving decision-making process (e.g. lack of time or expertise to search for, access, and interpret scientific knowledge), cultural and work-flow differences between science and policy fields, institutional disincentives (e.g. the academic mantra of "publish or perish"), and inadequate resources such as time, money, or capacity (Karcher *et al*., 2022). In SPMAML and "Projeto Orla" (Brazil), workshops were carried out to overcome such cultural differences; these spaces allowed stakeholders to share knowledge and information after establishing a "common language". Though this can take some time, determining which communication challenges to overcome while stakeholders are present can lead to a stronger, lasting science-policy relationship.

Panellists identified the need for more EOPs to mentor ECOPs in bridging the science-policy interface. This mentoring could include sharing EOPs' experience from previous inter- and transdisciplinary projects as well as their knowledge of the functioning of institutions and/or science policy

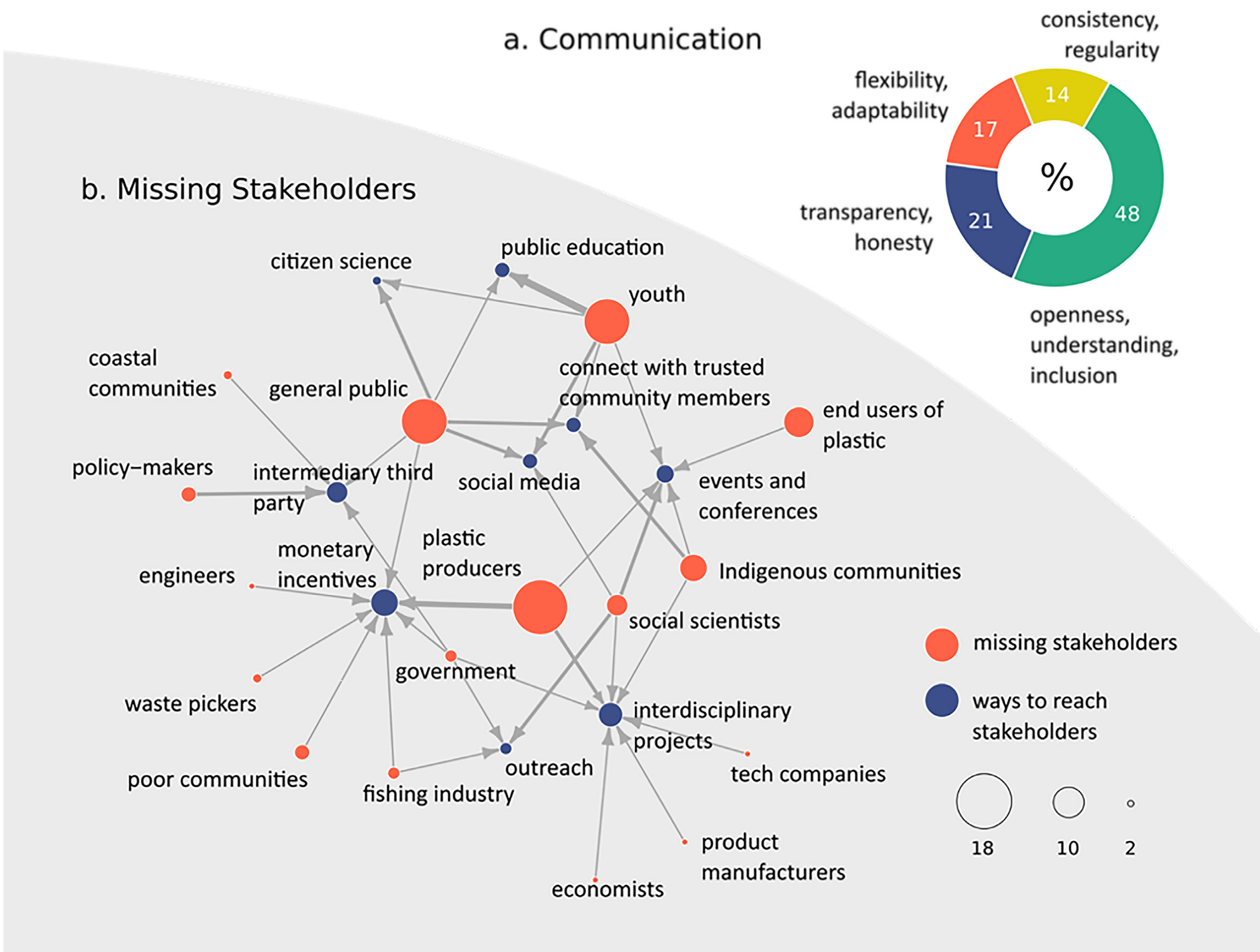

Figure 2. Communication strategies and missing stakeholders. (a) Features of effective communication. All comments on effective features of communication from our workshop's virtual whiteboard were pooled, where the percentage reflects the proportion based on communication-related comments made by the workshop participants. (b) Network showing the number of comments indicating missing stakeholders (red bubbles) throughout all sessions in our workshop, and arrows pointing to suggested approaches for including them (blue bubbles). Only missing stakeholders mentioned more than once were counted.

interfaces, opening doors to new professional and personal opportunities, funding schemes, and networks of key stakeholders within and outside academia. For example, this is the goal of the UN-endorsed ECOP Programme's task force, OceanBRIDGES (Bridging Ocean Research, Innovation, and Diversity among Generations of Experts and Stakeholders). Another example is the BlueMed Ambassadors' Programme, supported by the intergovernmental BlueMed Research and Innovation (R&I) Initiative for blue jobs and growth in the Mediterranean area (www.bluemedinitiative.eu). This programme's objective was to engage and coach a group of highly motivated young people from non-EU Mediterranean countries, to share the BlueMed vision in their national contexts and set the grounds for the development of a pan-Mediterranean network of "BlueMed Ambassadors".

Communication during public engagement projects

For projects that would like to include the input of community members, it is advisable to define appropriate communication channels at the beginning of the project. For example, informal networking, face-to-face virtual meetings, online workshops, and round-table discussions could all be efficient forms of communication. When science intends to support grassroots actions or work with indigenous community groups, scientists can also consider understanding their organizational culture to host meetings, presentations, and tailored ways to foster engagement with specific groups of people while respecting their common practices (e.g. Styres *et al.*, 2010; Koster *et al.*, 2012).

With smartphones being widely used even in remote areas around the globe, specific tech-based communication strategies could also be designed, such as using social media to widely reach local communities and increase their awareness of plastic pollution (Belontz *et al.*, 2019; Andrea *et al.*, 2020). Using social media to engage with younger generations has greatly improved and enhanced access to scientific information, irrespective of the person's background (Murri *et al.*, 2020), especially when language and visuals on these platforms are appealing to this audience (Fischer *et al.*, 2022; Shah *et al.*, 2022).

Missing stakeholders

The final question posed to our workshop participants was: based on the status quo of research on ocean plastic pollution, which groups have been absent from multi-stakeholder projects and, more importantly, why are they missing? We also asked how the academic community can reach and include any missing stakeholders.

Throughout the workshop, we saw the importance of including the Global South as well as other low-income nations in plastic pollution research, as they are often burdened with high waste volumes (including those exported from foreign countries, e.g. Gündoğdu and Walker, 2021). Specific groups of missing stakeholders (e.g. waste pickers, engineers, and school teachers) will be discussed below, according to the different scenarios addressed. Such collaborations ensure cross-cutting ocean plastic solutions that combine all experts' expertise and experiences. Plastic producers, youth, and the general public (with a focus on indigenous, coastal, and low-income communities) were also identified as missing stakeholders, along with a need to bridge the gap between social and natural scientists.

Specific modes of suggested engagement differed by stakeholder group, with public education, citizen science, and social media suggested as tools to engage youth and the general public, whereas interdisciplinary projects and financial incentives were suggested as better means of engaging industries and companies (Figure 2b). The network of stakeholders and tools presented here is not exhaustive but does give an awareness of the diversity of missing stakeholders, as well as the need to actively engage different groups in an effective manner. This mapping exercise can be used as a starting point to critically assess the stakeholders present in a project and ask questions about who could be missing and how they might be included. Strategies for including missing stakeholders can often be inferred based on the reasons for their exclusion. For example, scientists and others may hesitate to reach out to plastic producers because of a perceived lack of awareness, interest, or transparency. Other stakeholders, such as indigenous, coastal, and low-income communities, may be more broadly excluded because of prejudice, oppression or geographic, language, and/or other accessibility barriers.

Missing stakeholders in technology-driven projects

The development of physical technologies for monitoring or mitigating ocean plastics occurs in many different environmental compartments, for example, space (Topouzelis *et al.*, 2019), airspace (Cocking *et al.*, 2022; Gonçalves and Andriolo, 2022), the ocean surface (Sterenborg *et al.*, 2019), or undersea (Fulton *et al.*, 2019; Broere *et al.*, 2021). These operations require advanced technology with platforms carrying specific sensors and instruments to monitor ocean plastics. The stakeholders missing from a technology perspective can be the space industry, citizens, businesses, governmental agencies, and nations of different development and income levels. The key barriers for ocean plastic researchers engaging other stakeholders may include cost, the long-term demands of technology development, and the technical expertise required.

Another issue is the time-scale required to develop new technologies. As a shortcut, many technologies in use today are adapted from existing technology that was not initially intended for plastic monitoring. One example is satellites using multiband infrared imaging that can be used to detect floating plastic debris, even if these sensors were not originally developed for this goal (Biermann *et al.*, 2020; Topouzelis *et al.*, 2021). However, if satellites and other platforms, such as drones or surface vehicles, could be specifically designed for monitoring plastics, they would be much more effective in doing so. Efforts in this regard are already underway with programmes such as the Discovery Campaign on Marine Litter, supported by the European Space Agency's (ESA) Discovery and Preparation programme (https://esamultimedia.esa.int/docs/preparing_for_the_future/Discovery_marine_litter_results.pdf).

To go beyond co-opting existing technologies, research efforts require sustained funding to develop technological solutions where ocean plastic researchers are engaged from the start. When addressing ocean plastic research, natural scientists need to critically inform the design and function of the technology, requiring collaboration with experts in cybernetics, engineering, and aeronautics. As such, technology experts can be considered missing stakeholders in ocean plastic research. Some examples exist such as Ocean Diagnostics and Pirika Co. (https://en.corp.pirika.org/), start-up companies developing advanced sampling equipment for microplastics; however, fit-for-purpose samplers and other monitoring technologies are not yet the norm. If collaborative, innovative solutions developed by technologists and natural scientists are effective and scalable, this would enable the inclusion of other missing stakeholders, such as governmental agencies, for regular monitoring schemes or mitigation measures. Either in the case of existing technology or in the creation of new ones, governmental agencies should be included to legislate on their proper use, considering, for instance, that the established law with respect to drones and privacy is still underdeveloped (Nowlin *et al.*, 2019).

Lastly, technology can be a powerful uniting force for the sharing of data and tools that can enable the inclusion of a variety of stakeholders. Sourcing data from the general public through community science initiatives (i.e. citizen science) using apps for reporting beach litter, for example, can both increase understanding of the plastic problem and improve ocean literacy, enabling at the same time the collaboration of citizens, researchers, and policymakers simultaneously (Nelms *et al.*, 2022). Platforms like Plastiverse (www.plastiverse.org), Litterbase (https://litterbase.awi.de/), and the National Oceanic and Atmospheric Administration (NOAA) National Centres for Environmental Information (NCEI) microplastics database (https://www.ncei.noaa.gov/products/microplstics) were mentioned by participants as open science repositories. Sharing tools, data, and new developments can connect and inform stakeholders, enabling the participation of stakeholders who may lack infrastructure or financing. Open access to satellite imagery (https://www.sentinel-hub.com/), analytical tools for plastic identification (Primpke *et al.*, 2020; Cowger *et al.*, 2021), and toxicity assessments (Thornton Hampton *et al.*, 2022) all contribute to making research more accessible, thus further enabling the participation of a wider array of ocean plastic stakeholders.

Missing stakeholders in the science-policy interface

Participants from the workshop emphasized that a more diverse and equitable group of voices should be included to discuss policies that address and manage the global plastic pollution crisis. Hence, from the policy perspective, the missing stakeholders can be local and national governments, ocean plastic researchers, young people, and local community members. As we aim to reduce marine plastic pollution during the

Ocean Decade and develop global agreements (e.g. UNEA 5.2 in Nairobi, March 2022), underrepresented, low-income, or forgotten stakeholders must be necessarily involved in policy development and implementation, since they can often be the most affected by such issues.

The youth and community members (including local, traditional, and indigenous leaders) were also identified as missing stakeholders in the science-policy interface, especially if they are greatly affected by plastic pollution. If a certain policy-driven project based on ocean plastic research is successful, stakeholder feedback from the affected communities is a necessary step to determine follow-up work. To include their voices, continuous dialogues for feedback, citizen science, and social media content were all tools suggested in the workshop to be incorporated into the projects and actions to solve ocean plastic pollution via policy-making.

The United Nations Environment Assembly (UNEA) offers an avenue for such involvement in the ongoing UNEP Treaty negotiations through the Global Major Groups and Stakeholders Forum (GMGSF) (https://www.unep.org/civil-society-engagement/participation-and-engagement/engaging-un-environment-assembly-and-member). Major groups that are often underrepresented can and are encouraged to register for accreditation (https://www.unep.org/civil-society-engagement/accreditation?_ga=2.31071039.1257601202.1676170932-1569245974.1668754504) to participate in sessions of the UNEP assembly and their subsidiary organs, such as Regional Consultative Meetings. The major groups include "Children and Youth", "Indigenous Peoples and their Communities", "Women", and "The Scientific and Technological Community", amongst others. The communication tools mentioned above can be a major pathway to ensuring missing stakeholders are aware of avenues such as the GMGSF to participate in shaping policy.

Missing stakeholders in public engagement projects

During public engagement projects, the target audience is the "general public", which encompasses everyone. Reasons for "missing" certain groups of the public (meaning that they do not receive scientific information) could be due to a lack of access to information, interest, or awareness. For stakeholders negatively affected by ocean plastic pollution, improved engagement and ocean literacy can be crucial for identifying solutions (Worm *et al.*, 2021). Examples of stakeholders that might be more challenging to interact with include children, local marine users (e.g. small-scale fisheries, tourist operators, etc.), waste pickers, recyclers, and traditional or indigenous people. According to the workshop participants, the contribution of these stakeholders could be transformative, for example, by providing innovative ideas for practical, tailor-made plastic pollution solutions that are not considered by scientists or by changing their behaviour towards reducing plastic usage and preventing littering (in areas where adequate waste management systems are available).

During the workshop, certain strategies for increasing and improving public engagement with missing members of the public were suggested. These include school education to improve ocean literacy among children and citizen science to engage with local communities. For example, primary and secondary school curricula could include specific classes focused on the importance of a healthy, sustainable ocean and environment. This can be facilitated by external organizers; for example, the EU4Ocean Platform (hosted by the European Marine Board) works with educators to connect, collaborate, and mobilize efforts towards ocean literacy in European schools.

Community science projects can be practical and powerful tools for data collection as well as raising awareness and stimulating behavioural change. For example, beach clean-ups and citizen science monitoring programmes are already widely and successfully applied in some regions of the world (e.g. Serra-Gonçalves *et al.*, 2019). The Refilwe Matlotlo (https://refiloemofokeng.wixsite.com/website) non-profit organization in South Africa and Plastic Punch NGO in Ghana (http://plasticpunch.org/) work to promote ocean literacy through ocean cleanups and community building, with activities based on scientific findings. The inclusion of local communities in the scientific process is valuable for gaining community interest and further strengthening the general support for ocean conservation issues (Kelly *et al.*, 2022). Creating collaborations between scientists and lawyers working on the Rights of Nature and ocean stewardship could be a strategy for developing this idea further (e.g. Harden-Davies *et al.*, 2020). Making data and scientific findings that are easy to visualize and understand on publicly available websites can also be a facilitator to disseminate information. For example, UNEP launched the Global Partnership on Plastic Pollution and Marine Litter in 2012, a multi-stakeholder group to bring together all actors working to prevent plastic pollution and marine litter. Their website shares all publicly available plastic data on their digital platform and uses maps to easily locate data sources.

ECOPs as missing stakeholders

As a final remark, across all sessions, youth engagement in the marine pollution space was identified as critically important. Panellists in later career stages encouraged the inclusion of ECOPs in the policy space to increase the diversity of new, creative voices working towards ocean plastic solutions. ECOPs across the workshop self-identified to be willing to collaborate and engage in these youth and educational spaces, thus highlighting the hugely valuable contribution ECOPs can offer in educating, elevating, and supporting the voices of young people as the next generation of Ocean Leaders (Kelly and Singh, 2021; Satterthwaite *et al.*, 2022). Despite many challenges (e.g. Schadeberg *et al.*, 2022), the inclusion of ECOPs is already highly encouraged in ocean sciences (Sobey *et al.*, 2013; Brasier *et al.*, 2020). Efforts have begun to provide ECOPs with decision-making opportunities by being on ocean programme steering committees or organizing global stakeholder engagement events (such as the Ocean Plastic Workshop in 2022). Inter-generational networks (such as the ECOP programme's OceanBRIDGES) can foster the much-needed two-way dialogue between ECOPs and EOPs, which values and recognizes the knowledge, expertise, and enthusiasm of ECOPs to develop innovative ocean plastic solutions. The future of ocean plastic research should continue to work towards creating inclusive spaces to further enable ECOP engagement across the world.

Conclusion

Our paper aims to provide guidelines and recommendations for knowledge exchange between ECOPs, EOPs, and other stakeholders within and beyond academia working on the topic of ocean plastic solutions. Following interactive discussions held during a workshop in April 2022, we focused on three main questions: (i) What is the role of scientists in a multi-stakeholder project? (ii) How should scientists communicate with other stakeholders? (iii) Which stakeholders are missing in collaborative projects, and why are they missing? We also focused on three themes for ocean plastic solutions: innovative technology, policy-making, and public engagement. The key suggestions for successful stakeholder engagement projects are: (1) scientists should take on the role of knowledge brokers who provide credible, transparent, and jargon-free information; (2) communication between stakeholders is critical and depends on suitably designed communication channels that encourage openness, respect, and trust after setting expectations; and (3) missing stakeholders, such as ECOPs, people from the Global South, finance bodies, industry, and policymakers, must be invited from the start and engaged throughout the project duration. These recommendations are especially timely now that negotiations for a legally binding global UN treaty addressing the full life cycle of plastics are finally ongoing. The workshop highlighted that stakeholder engagement projects are a promising strategy for implementing actionable ocean plastic solutions based on solid scientific knowledge. With the guidelines we have outlined for the co-creation of science (based on the needs and interests of all stakeholders), the plastic treaty and future collaborative projects can be even more effective in tackling fundamental sustainability goals.

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Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Conflict of interest

The authors declare no conflict of interests.

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Author contributions

K.L.L. and D.L.: conceptualization; R.P.M., A.F., M.B.A., I.B., I.C., K.L., N.B.M.Z., E.S.N., and P.S.P.: investigation; R.P.M., A.F., M.B.A., I.B., I.C., K.L., N.B.M.Z., E.S.N., P.S.P., and G.S.: writing—original draft; R.P.M., A.F., G.S., K.L.L., D.G., S.H., K.W., T.M.A., C.S.G., A.Z., T.S.E., P.S.P., H.C.E., and D.L.: writing—review and editing; K.L.L.: funding acquisition; and K.L.L., G.S., and D.L.: supervision.

Data availability

This study did not generate unique materials, datasets, or code. Further information and requests about the workshop should be directed to Delphine Lobelle (delphine.lobelle@gmail.com).

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