MARINE OBSERVATIONS AND SOCIETY: PATHWAYS TO IMPROVE PUBLIC ENGAGEMENT AND THE SCIENCE-POLICY NEXUS

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MARINE OBSERVATIONS AND SOCIETY: PATHWAYS TO IMPROVE PUBLIC ENGAGEMENT AND THE SCIENCE-POLICY NEXUS

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Editorial: Marine Observations and Society: Pathways to Improve Public Engagement and the Science-Policy Nexus

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Keywords: marine observations, ocean science communication and education, SDGS, ocean literacy, citizen science, science, policy and governance

Editorial on the Research Topic

Marine Observations and Society: Pathways to Improve Public Engagement and the Science-Policy Nexus

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Climate change, and the resulting global warming and acidification of the ocean is causing change to marine environments (United Nations, 2017; IPCC 2021) with serious implications for global ecosystems, food security and ocean economies (Allison and Bassett 2015; Pörtner et al., 2019). To ensure a sustainable future for all, there is a need to understand these changes and their impacts on the provision of services from the marine environment. This will also require the identification of knowledge gaps and the capacity needed to develop effective and sustained ocean observation systems that support the development of relevant responses (Evans et al., 2019; Wisz et al., 2020).

Improved societal understanding of the services provided by the ocean, and how humans affect the ocean are at the core of the development and implementation of sustainable decision-making and is particularly important within the context of achieving the globally agreed sustainability targets of the Agenda 2030 for Sustainable Development (Kelly et al., 2021). In order to shift current decision making and policy development to frameworks where the ocean and the services it provides to humans are considered at every step, universal understanding across all aspects of society is needed (Wisz et al., 2020). This will require multiple approaches and strategies, tailored to individuals, sectors and regions that incorporate many disciplines, methods and technologies as many of the papers in this special issue highlight.

A DIVERSITY OF APPROACHES TO IMPROVING OCEAN UNDERSTANDING IS KEY FOR BETTER DECISION MAKING

This special issue brings together differing viewpoints and processes aimed at improving societal ocean understanding through a collection of ten papers. It provides a number of suggestions that, if implemented, would lead to greater access to information that is fit-for-purpose and engagement by multiple sectors. The contributions can be grouped into four themes: citizen science; science, policy and governance; outreach and education; and communication approaches.

Citizen Science

Coordination and compilation of information on citizen science programs is often not organized across regions, making it difficult to assess their impact and effectiveness. Garcia-Soto et al. collated information on projects occurring in the North Sea and assuming similar densities of projects across coastlines, estimate the potential extent of projects across Europe and their growth through time. They conclude that uptake of emerging technologies (such as mobile phone applications) is likely to increase the number of projects and associated engagement, and that there is scope for growth in the focus of marine citizen science initiatives.

Dalby et al. investigated the motivation and barriers to engagement of participants in citizen science. They found that while citizen science has the potential to become an effective tool for monitoring and conserving marine ecosystems, understanding the limits of citizens' engagement and their ability to collect large quantities of marine data is also important.

Science, Policy and Governance

Linking science to policy and governance for supporting informed decision making and development of effective adaptation strategies requires collaborative partnerships to ensure information provided is fit for purpose. Hetherington and Philips provide a series of practical steps for improving the delivery of science into processes for informing legislative decisions and effective policy. They stress that bridging science and policy involves ongoing engagement to ensure effectiveness.

Evans et al. explore the knowledge brokering role of the World Ocean Assessment in transferring complex scientific knowledge into useable products for society and some of the associated challenges in delivering information at such a scale. They identify that wider engagement with member states, the scientific community and marine industries is needed for the co-development of assessment inputs with managers, regulators and holders of maritime industry and business data in order to improve future assessments.

Through the examination of three case studies where Transnational Municipal Networks (TMNs) had been used to advance the incorporation of climate change adaptation and mitigation into marine governance, Dumala et al. found that spatial identity determined the scale and innovativeness of a networks' operation. The effectiveness of strategies and actions jointly developed by networks, depend on the allocation of human resources and on the level of commitment of the involved cities in providing leadership into such processes.

Outreach and Education

There is increasing recognition of the importance of science communication in informing science literacy and policy. Arthur et al. found that publicly funded national research facilities, such as Australia's Marine National Facility have an essential role to play in shifting from the provision of traditional research activities only, to targeted education and outreach via marine education, on-board training and engagement with a range age groups, societal sectors and ocean stakeholders.

Zielinski et al. found that increased incorporation of environmental subjects in school education, including those that consider uncertainty is needed to support the development of collaborations between researchers, data managers and educators to improve overall delivery of scientific information to society. To achieve this they propose a pathway that takes advantage of the technological abilities for environmental data collection, storage and processing, global and regional research and incorporates good practices in ocean literacy and education.

Communication Approaches

Communication approaches to environmental problems are multi-faceted and challenging, particularly when impacts are slow to become evident. Using lessons learned in communicating the impacts of climate change, Canfield et al. identify that sufficient training of scientists in communicating their research and framing messaging so that it can be understood and used by diverse audiences is essential for better communicating the nutrient pollution impacts and catalyzing action.

Although understanding of the need for protective measures from environmental threats and associated actions has increased, Mamzer et al. identify that there is still a need to educate the broader audience about the urgency of responding to these threats. They found that due to their specificity, that understanding of polar regions could act an indicator of current interest in sustainability and effective environmental protection.

Paterson et al. detail the development and installation of an art-science collaboration ('Catching a Wave') as a transdisciplinary approach to engaging multiple audiences with global environmental challenges. In doing so, they highlight that collaborative arts and science projects can enhance transformations in understanding and action by encouraging decision making that engages with emotion and intuition as well as cognition as a motivation behind change.

CONCLUSION

Providing society with a holistic understanding of the role of the ocean and the impacts of human activities on the services it provides is crucial in order to catalyze the behavioral change required for future sustainability. Science, communication and education need to come together via broad collaboration to apply integrated and cross-sectoral approaches to effectively share information on the ocean, the changes occurring, associated effects on communities and approaches for mitigating changes and adapting to these changes. Overall achievement of Agenda 2030 relies on the implementation of a range of multidisciplinary and innovative approaches to improving ocean understanding that leads to universal valuing of the ocean and the role it plays in sustaining a future for all.

AUTHOR CONTRIBUTIONS

All authors contributed to the preparation of the Editorial text, participated in the discussions on its form and final shape of the text.

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Examining the Potential of Art-Science Collaborations in the Anthropocene: A Case Study of Catching a Wave

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There is a disconnect between ambition and achievement of the UN Agenda 2030 and associated Sustainable Development Goals that is especially apparent when it comes to ocean and coastal health. While scientific knowledge is critical to confront and resolve contradictions that reproduce unsustainable practices at the coast and to spark global societal change toward sustainability, it is not enough in itself to catalyze large scale behavioral change. People learn, understand and generate knowledge in different ways according to their experiences, perspectives, and culture, amongst others, which shape responses and willingness to alter behavior. Historically, there has been a strong connection between art and science, both of which share a common goal to understand and describe the world around us as well as provide avenues for communication and enquiry. This connection provides a clear avenue for engaging multiple audiences at once, evoking emotion and intuition to trigger stronger motivations for change. There is an urgent need to rupture the engrained *status quo* of disciplinary divisions across academia and society to generate transdisciplinary approaches to global environmental challenges. This paper describes the evolution of an art-science collaboration (Catching a Wave) designed to galvanize change in the Anthropocene era by creating discourse drivers for transformations that are more centered on society rather than the more traditional science-policy-practice nexus.

Keywords: transdisciplinarity, sustainability, art-science, Anthropocene, SGD14

INTRODUCTION

The world is at a turning point for sustainable development and there is an evolving need to identify and enact new pathways to action in the face of constantly shifting biophysical and social realities (Randers et al., 2018). The aspirational and collective nature of the UN Agenda 2030 and its Sustainable Development Goals (SDGs) (United Nations, 2015) has been used as a central tenet to inspire numerous meaningful and impactful transdisciplinary partnerships, including between art and science actors (Brennan, 2018; van der Vaart et al., 2018). The SDGs have been used to galvanize, among others, the role of youth and innovation (Bastien and Holmarsdottir, 2017), engagement with industry and business (Scheyvens et al., 2016; Weber, 2018), sports (Lemke, 2016), and gender equality (Fredman et al., 2016). This suggests that actors within both community and political spheres are attempting to take advantage of the holistic and optimistic appeal of the SDGs to stimulate social action (McAfee et al., 2019). In fact, there is a growing recognition that overall achievement of the SDGs depends not only upon responsible economic development administered through the lens of environmental sustainability, but perhaps more significantly, through enhanced social inclusion and justice (Ensor et al., 2018; Patterson et al., 2018; Fleming et al., 2019). The literature is beginning to reflect a more systematic consideration of social justice implications of climate change responses at national and subnational levels, including differential abilities to adapt (Paavola and Adger, 2006; Adger et al., 2017) as well as the need to ensure that those least able to influence the process but often most affected are heard (Fleming et al., 2019).

Despite this recognition, there is a gap in the current conceptualization of the UN Agenda 2030 and the SDGs and implementation at scale (Le Blanc, 2015; Stevens and Kanie, 2016; Stafford-Smith et al., 2017; Blythe et al., 2018; Scherer et al., 2018), across the Global North-South binary (Iqbal and Pierson, 2017; Hayward and Roy, 2019; Horner and Hulme, 2019) and especially when framed within the concept of the Anthropocene (Lim et al., 2018). This gap has two origins; (i) the knowledge and science needed to achieve the SDG targets and indicators and (ii) the engagement of the whole public in SDG delivery. Both of these origins are easily demonstrated in coastal and ocean systems: systems that are under ever increasing pressure from direct pollution and eutrophication, climate change, and fishing and aquaculture (Borja et al., 2017; Visbeck, 2018). Despite continued discourse around the importance of these spaces, epitomized by SDG14:Life below Water, little traction has been gained when it comes to shifting behaviors or resonating with society on a broader scale (Cormier and Elliott, 2017; Fleming et al., 2019). Recent politically focused engagement activities have shown that SDG14 is almost universally considered the least important of the SDGs (Custer et al., 2018). These results were derived from a questionnaire sent to elected politicians, bureaucrats, non-profit and humanitarian executives, and business leaders from 126 low- and middle-income countries in South and Central America, Africa, Europe, and Asia. They demonstrate a clear severing between the rhetoric of scientific research agendas (ICSU and ISSC, 2015; Plag, 2018; Visbeck, 2018) and reality around the lack of a perceived political importance (Custer et al., 2018). This is despite the fact that fish and seafood are a primary source of protein for more than one billion of the poorest people on Earth (Huelsenbeck, 2012; Béné et al., 2016) and the goods and services from coastal and marine ecosystems being estimated to contribute about $2.5 trillion (USD) to the global economy each year with a total asset base of at least $24 trillion (USD) (Hoegh-Guldberg, 2015). For instance, Europe's coastal regions are home to 214 million people and generate 43% of EU GDP, and the blue economy is regarded as a growth sector, with opportunities both in established sectors like tourism and shipbuilding, and in emerging areas like ocean energy or the blue bio-economy (European Commission, 2019). Yet, coastal landscapes are under considerable pressure and change, for instance, from sea level rise changing unalterably the physical, social and economic geography of coasts (Ramesh et al., 2015) or the marine plastic issue (Haward, 2018; Villarrubia-Gómez et al., 2018). This disconnect is further illustrated by a number of SDG interlinkages tools and national governmental documents that either fail to feature SDG14 or coastal and ocean spaces, such as UNEP's Frontiers 2018/19: Emerging Issues of Environmental Concern report (UNEP, 2019), or show poor reporting across all environmental SDGs (e.g., Sachs et al., 2018; Villarrubia-Gómez et al., 2018).

In a time of global environmental change and uncertainty, knowledge acquisition, transfer, and application for global societal change is critical, and a call for innovation, including arts and the humanities, to foster action at all levels of society forms part of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030) (Claudet et al., 2020). This paper examines a process to build an inter- and *trans*-disciplinary art-science collaboration to create such opportunities to elucidate a mechanism that can galvanize change by creating discourse drivers for transformations that are more centered on society rather than the more traditional science-policy-practice nexus. A case-study of an iterative project, *Catching a Wave*, designed to demonstrate the co-design potential of ocean and coastal sustainability while providing levers for both cultural identity and innovation is presented. In addition, the process of transdisciplinarity to create such transformational pathways to impact are also examined. Finally, a critical assessment of the potential of catalyzing social change through an integrated art-science approach is discussed.

CONTEXT FRAMING

Human pursuit of coastal sustainability in the Anthropocene requires transformative social and economic pathways that navigate toward sustainable development co-created with the intended beneficiary communities (Pelling et al., 2015; Future Earth Coasts, 2018). There is increasing awareness that existing assessment processes that monitor the status of environmental and societal components of coastal systems cannot on their own deliver the knowledge for transformations to more sustainable pathways of coastal use (Ajzen, 1985; Benham and Daniell, 2016; Marques et al., 2016; Comte et al., 2019). Problem to solution formulation is not simply an issue of multi-disciplinary approaches but must account for social and cultural values, norms, and priorities that differ greatly based on a variety of issues (Leiserowitz et al., 2006; Jefferson et al., 2015; Bennett, 2016; Mayer et al., 2017). This variation is also reflected in the ways that people learn and communicate knowledge, shaped by new forms of communication (Shi et al., 2016; Zareie and Jafari Navimipour, 2016), especially around climate and sustainable

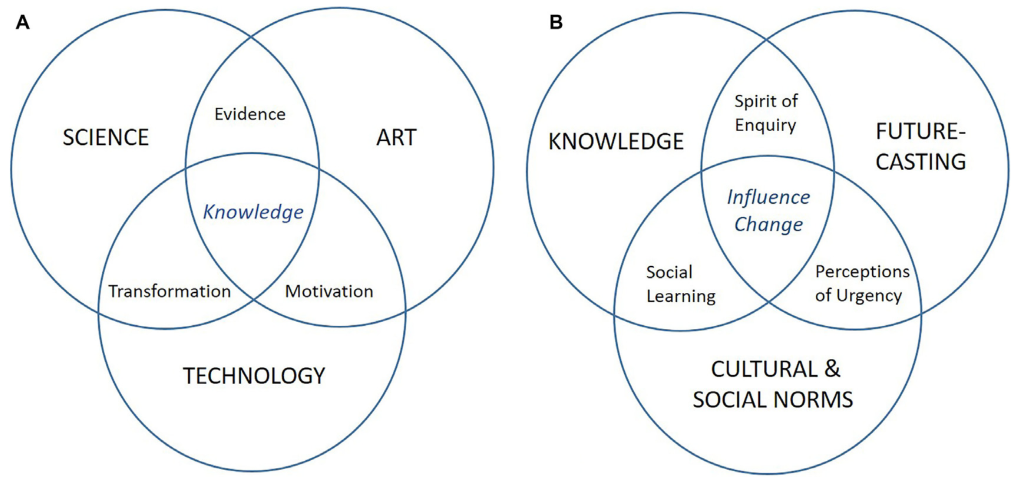

FIGURE 1 | (A) Both arts and sciences increasingly employ technology as part of their methodologies but by working collaboratively the opportunity to combine motivational aspects of decision making by individuals and society promoted by art with the transformations that science seeks through the persuasive 'power' of facts is likely to lead to a deeper held knowledge that reflects cognitive with emotion and intuition in decision making (49). **(B)** Both knowledge and 'imagination' to 'see' better futures or understanding of the past combine to manifest more impactful and meaningful avenues for enquiry and potential innovative solution spaces that art, science, or technology could achieve alone. When coupled with the norms and cultural values held within society, knowledge can be instrumental in enabling deeper, social learning that allows for new behaviors to be acquired creating a negotiated space that allows for change (70). These elements all are necessary to catalyze the large-scale shifts in behavior across society that are needed to enable sustainability.

development issues (Ballantyne, 2016; Moser, 2016). This reality means that knowledge in combination with learning, both social and individual, is critical in catalyzing the sense of urgency necessary to influence change (**Figure 1**) (van Mierlo and Beers, 2018; Goyal and Howlett, 2019). Therefore, in order to spark global societal change toward future sustainable pathways at all scales, the mechanisms through which science, knowledge and social learning are employed and engaged with also have to be more responsive to social differences and inputs (Ensor and Harvey, 2015; Cummings et al., 2018; Wehn and Montalvo, 2018). Existing processes need to respond to a variety of ways of knowing that lead to different contexts of application requiring new processes to integrate and engage with these differences from the start (Brugnach and Ingram, 2012; Hawkins et al., 2015; Eldred, 2016).

In this paper, transdisciplinarity is taken as providing a framework that transcends disciplinary boundaries to develop holistic and transformative solutions where the outcome extends beyond interdisciplinary approaches to create something completely new providing space for social transformations as well as governance ones (Defila and Di Giulio, 2015; Klenk and Meehan, 2017; Schneider et al., 2019; Norström et al., 2020). Such approaches can embed social justice at their core and also allow for geophysical, ecological, philosophical, cultural, and emotional connections to ocean and coastal spaces to be realized at different scales (Brown, 2015; Olsen et al., 2016; Irwin et al., 2018). They also embrace concepts such as co-production in a practical rather than an analytical sense, focusing on the intentional act of engaging non-scientific actors in the process of scientific knowledge production, which has increased this responsiveness (van der Hel, 2016). Examination of such enabling mechanisms, and potential innovations and transformations to existing social structures, can shed light on how public opinion is shaped, how perceptions are formed across diverse areas in society, and how to mobilize change across scales (Leiserowitz et al., 2006; Miller et al., 2014). This can provide pathways to increase the impact factor of science and knowledge through traditional and non-traditional communication routes (Reed et al., 2010).

Art-Science Collaborations

Art and science literature make clear that both 'disciplines' share a common motivation and goal to understand and describe the world around us (Sleigh and Craske, 2017), and are engaged in concepts of reflection across all elements of society to effect changes in behavior in individuals and society. In addition, both art and science provide avenues for enquiry and communication, impacting different audiences through the generation of a multiplicity of resonate narratives (Chabay, 2015). Art, in its many and varied forms, has the liberty and ability to generate shifts in social perceptions and behaviors in ways that science and data alone currently do not (Pearce et al., 2003; Eldred, 2016; Brennan, 2018), providing a complementary pathway for engagement. However, despite common goals, more and more literature has been generated around how the increasingly engrained *status quo* of disciplinary divisions across academia and society is actively contributing to this separation (Leach, 2005; Sleigh and Craske, 2017). It has been postulated (Trondle et al., 2019) that combined collaborative arts and sciences projects can enhance transformations by encouraging decision making that engages with emotion and intuition as well as cognition as a motivation behind change (Soosalu et al., 2019). Numerous benefits of bringing together the methodologies and practices of science and technology with art in its many forms in a transdisciplinary cross-over approach can be identified. These include the creation of participatory and discourse spaces that generate evidence and enable transformation in practice (Fischer, 2006; Oliver and Boaz, 2019) as well as shared and negotiated understanding of the meaning and implications of existing knowledge (Born and Barry, 2010; Gibbs, 2014) and increased innovation in knowledge transfer (Cornell et al., 2013) (**Figure 1**).

Although challenges to the great divide of art and science, hallmarked in C. P. Snow's 1956 model of "two cultures," are not new (Snow, 1956), art-science collaborations have experienced a surge of interest in recent years (Born and Barry, 2010; Trondle et al., 2019). Malina (2001) used the term 'new Leonardos' in his effort to capture ways that he saw people charting new professional territory synthesizing art, science and technology. Describing the information arts, Wilson (2002) heralded an "essential rapprochement" between "two great engines of culture." Since then, across a spectrum of sectors and activities, the involvement of artists in the production of science and technology is no longer rare, although it is far from routine. Collaborations have enabled technological innovation (Broadhurst, 2007; Eldred, 2016), urban environmental rejuvenation (Ingram, 2014; Whitehead, 2018), data visualization (Cox, 1991, 2004; Born and Barry, 2010; Woodward et al., 2015), new models for education and work (Ghosh, 2005; Gurnon et al., 2013; Hawkins et al., 2015), the role of technology in society (da Costa and Philip, 2008) and even national competitiveness (Huggins and Clifton, 2011). Key examples that can be drawn on with respect to SDG14 include public discussion on the impacts of sea-level rise and changing ocean health on coastal and island communities (Ingram, 2014; Straughan and Dixon, 2014; Brennan, 2018), ocean ice (O'Connor and Stevens, 2018), and the impacts of ocean plastics (Carnell et al., 2020). Some of these collaborations are well established, such as the United Kingdom-based Cape Farewell project that has focused on climate change and the Arctic with the aim of fostering a cultural discussion (Ingram, 2011).

ENACTING A TRANSDISCIPLINARY ART-SCIENCE PARTNERSHIP

In the context of the work described here, principles of transdisciplinarity were inculcated in the working of the project team and the design and implementation of workshops. For workshops, participation from outside of academic circles, including participants from outside of the research realm who bring additional worldviews and experiential knowledge necessary to address complicated and pressing social and environmental problem (Carew and Wickson, 2010; Defila and Di Giulio, 2015; Klenk and Meehan, 2017), was actively encouraged. For transdisciplinarity to achieve its own stated goals, there is a need to move beyond the inclusion of non-science disciplines, and particularly the arts, as 'add-ons' to accomplish outreach and communication goals (Brandt et al., 2013; Norström et al., 2020). Instead, integrating these disciplines into all aspects of the design, implementation and outcomes of projects can provide the necessary pathways to break through barriers of language to bridge between stakeholders across science, society and politics communities (Popa et al., 2015). Art is a means for stakeholders and knowledge providers, whatever their discipline, to discover their own meaning and new ways to convey their understanding to others, and provide an open platform to juxtapose potentially conflicting and contradictory perspectives.

Transdisciplinarity provides an opportunity to capture the creativity of art to bring cultural capital to science in the context of Snow's (1956) two-cultures debate (Sleigh and Craske, 2017) to address the increasingly complex challenges confronting sustainable development (Bernstein, 2015; Zafeirakopoulos and van der Bijl-Brouwer, 2018), currently framed by the UN 2030 Agenda (United Nations, 2015). This re-imagination is rooted in Barry et al.'s efforts to identify art-science collaborations through the lens of three logics of interdisciplinarity: accountability, innovation, and ontology (Barry et al., 2008; Born and Barry, 2010) where (i) accountability refers to the way in which scientific research is increasingly required to make itself accountable to society, (ii) innovation draws attention to scientific research needing to fuel industrial or commercial innovation and economic growth, and (iii) ontology discusses provoking change in both the object(s) of research, and the relations between research subjects and objects.

The ontological logic is the most critical in this construction, highlighting the reality that some art-science initiatives are focused on altering existing ways of thinking about the nature of art and science, as well as with transforming the relations between artists and scientists and their objects and publics (Born and Barry, 2010).

Catching a Wave Case Study

Concept Development

Catching a Wave (CaW), an iterative sea-level rise multi-media installation, has brought together a research consortium from four universities based in the United States, United Kingdom, and Ireland. CaW was deliberately conceptualized to act as a catalyst for constructing a transdisciplinary approach for shifting individual and collective mind-sets toward action for more sustainable oceans and coasts and the people who live, work, and interact within these spaces. Focused on five SDGs; SDG13: Climate Action and SDG14: Life below Water, SDG3: Good health and wellbeing; SDG15: Life on Land; and SDG17: Partnerships for the Goals. CaW was designed to increase awareness and resonance of the SDGs and oceanscapes with multiple audiences. While CaW specifically set out to transform the way in which actors, stakeholders, and society interact with ocean and coastal spaces, the process of message development has remained dynamic and driven by an iterative co-design process. Using the models described in Section "Context Framing" (**Figure 1**), CaW has coupled elements more aligned with knowledge generation in natural systems with technological applications and innovative practices to enable more effective translation of actions into products that seek to influence society and society interaction (**Figure 2**). CaW can therefore act as a translation lens for both knowledge and ways of knowing that

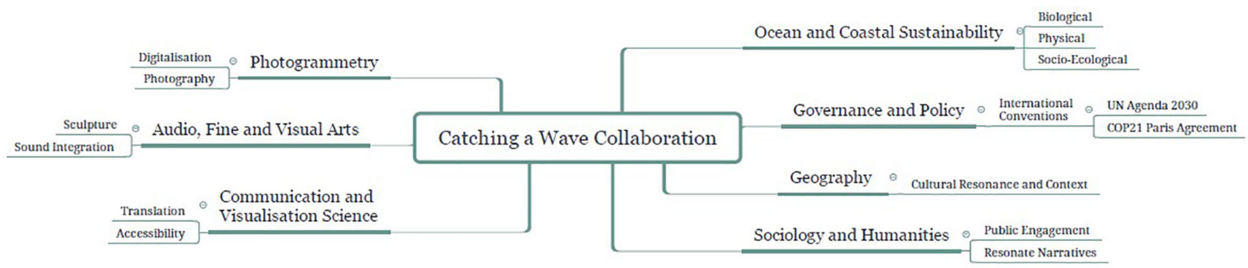

FIGURE 2 | The architecture for a transdisciplinary collaboration for shared knowledge generation elements that underpins CaW to reflect both cognitive and emotional elements that can support societal transformation for sustainability. The collaboration acts as an integrating interface between both disciplines of enquiry and communication technologies to develop products – in this case artistic representations of waves- to encourage and enable conversations between holders of different facets of knowledge, opinions and perspectives that might not otherwise take place, or would take place in a contested setting.

may help to catalyze both the spirit of enquiry as well as social learning over time.

Technical Development and Innovation

Initially conceived to create an artifact that would embody an exact moment in time, CaW focused on using "captured" waves made of glass in sculptural installations designed to communicate, in a novel way, information about climate change, sea level rise, ocean health and to publicize ocean-related research. These glass artifacts were to visually communicate the complexity of what is happening in a single wave at a single moment of time, and make a connection for the viewer to the intricacy of what was happening, on the surface and internally, in that wave[1].

Each wave was generated in a wave tank at the Coastal Studies Institute in Wanchese, NC, United States and photographed from a half-dome 360 degree rig of 16 Nikon D810 36.3 MP full frame digital SLR cameras, capturing as many wave surfaces as possible from a variety of angles. High-speed sync triggers were installed on cameras to synchronize the shutters to within 1/1000th of a second to ensure the cameras fired at precisely the same moment. Agisoft Photoscan Pro modeling software was used to reconstruct the location of the photographs and create three-dimensional (3D) point clouds made up of common points in each picture, resulting in one composite 3D digital image (**Figure 3**). Transparency and motion issues, caused by the nature of water itself, were solved by spreading sawdust on the water's surface. The sawdust provided the needed contrast and tracking surface for the 3D rendering software. This digital output was subsequently used to produce a 3D printed replication of the photogrammetrically captured wave. A flexible silicone mold was made of the 3D printout. Wax was poured into the silicone mold creating a wax positive of the 3D printout from which an investment mold was made (mixture of plaster and refractory materials, i.e., silica and grog) into which was placed cold glass (cullet), small colored powders and grains of glass (frit) to add colors that resembled water and sheet glass with text and images printed with glass enamels. The molds filled with this glass mixture were placed into an electric kiln and heated slowly to 1,460° Fahrenheit (794°Celsius) for 40 min then annealed at 900° Fahrenheit (482°Celsius) to remove stress and to make sure the glass is the same temperature at the core and at the surface. The glass is then cooled slowly in three stages to prevent cracking. After removing the mold from the kiln, the investment mold material is removed, and the glass polished with an eight step process (using a series of diamond grits, smoothing materials) until it is clear enough to see into the interior of the wave. To make the smaller waves the glass castings were cut into about 9–12 smaller pieces and each polished so that one can see into the interior of the glass.

[1]CaW video.

Message Development and Experience Contextualization

The initial concept of using waves as focal points to generate an emotional and behavioral reaction to ocean and coastal spaces was introduced during a pilot workshop at the *Society and the Sea* Conference in 2018 (**Figure 4**). The workshop engaged 20 self-selected conference participants whose interests were aligned to the conference theme of achieving ocean sustainability (specifically in the context of exploration of the value of the ocean and how that can be recognized, communicated and harnessed to contribute to the health, wealth and wellbeing of society). The purpose of the workshop was to engage with a community of interest from diverse disciplines, which included natural and social scientists as well as from the arts and humanities, who could share experiences and provide CaW with opinions on how to evolve art-science integration. This workshop blended both interactive (on-line tools Slido and Padlet and semi-structured discussions focused on linkages and communication, breaking down barriers and opportunity as part of a finding solutions exercise) and PowerPoint and video presentations centered on SDG14. Small hand-sized waves were distributed amongst the participants as a reminder of the workshop and a novel way of staying connected to the project. From the discussions several key messages emerged with respect to how an art-science collaboration could make Sustainable Development Goal 14 Life Below Water more prominent on peoples' agenda (Future Earth Coasts, 2020):

(1) One-size-fits-all to communicate science to other communities/disciplines does not work but requires a suite of media platforms to be used, and which allow others

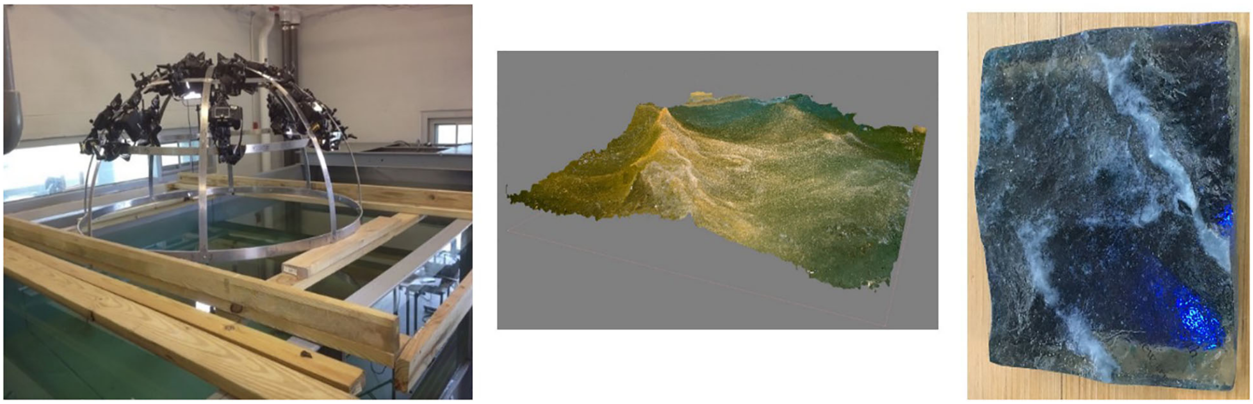

FIGURE 3 | The process of wave capture from technical through digital and physical forms (i) Camera rig designed for photographing the water, (ii) the resulting digital image of captured wave and (iii) a glass wave from above.

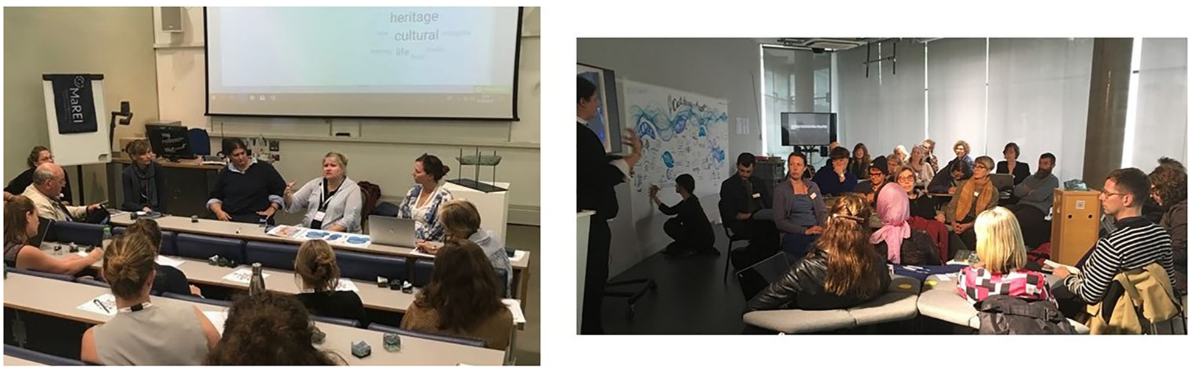

FIGURE 4 | Interactive CaW interactive workshops from (i) Society and the Sea, Greenwich (2018) and (ii) Art in the Anthropocene, Dublin (2019).

to become part of the conversation between specific events. However, it is important to exercise care when introducing 'new' types of media (e.g., Slido and Padlet) that could become a barrier to expression.

(2) Ensuring that workshops provide opportunity for participants to engage in the topic through a lens of their own work and experiences, rather than solely through the lens of the project being presented, is important.

(3) There was a proof-of-concept validation of the approach taken by the CaW project, including the use the glass waves, as a medium to engage and nourish conversations between disciplines that would not normally take place.

(4) The participants reinforced a need to interpret transdisciplinarity as an extension of interdisciplinarity to include stakeholders as practitioners of research (Klenk and Meehan, 2017) with a view to invoke the issue of social inclusion to ensure that those least able to influence political and social processes but often most affected are heard.

These outcomes from the first workshop informed a second iteration implemented during the *Art in the Anthropocene* (*AiA*) Conference in 2019 where a CaW installation was coupled with an interactive workshop run twice to accommodate the demand to participate (**Figure 4**). The two 2-h workshops were delivered at the Science Gallery, Dublin, to a total of 82 self-selected participants from principally artistic and social science backgrounds, but also included youth (below 16 years age), business and civil society. Given the nature of the conference, and un-like the Society and Sea conference, the background of the audience was not primarily environmentally, and coastal/sea, focused but more strongly focused on questions that concern the sustainability of the planet from a societal perspective (Catching a Wave, 2019). Using feedback from the first workshop and in an attempt to adapt the workshop to engage with a different audience CaW made a number of changes to the organization of the workshop, namely:

(1) To broaden the discursive space, this workshop series focused around the five pillars (5Ps) of Agenda 2030 – people, prosperity, planet, peace and justice, and partnership. These pillars have been used in the UN Agenda 2030 (2) to recognize the interlinked and integrated nature of the SDGs and the interconnectedness of factors and interventions that influence human development outcomes.

(2) The waves were approximately four to five times larger than the previously used hand-sized ones and displayed on five individual pedestals creating a space whereby the workshop participants were physically sitting amongst the installation during the workshop and being fully emerged in the exhibit
(3) The waves were modified to include;
    (a) Images and text relating to ocean health embedded into the glass waves fusing them so that they folded into the wave but remain legible through the polished sides of each wave and,
    (b) Sounds, both human and non-human, were incorporated to each installation piece. Sound, such as waves, dune birds, oysters clicking, and voices of both children and adults created an additional avenue to provide local context for the audience to connect to, as well as provoke an emotional connection to the ocean.
    (c) Participants were encouraged to leave any comments, observations, and thoughts behind on post-it notes on any of the pedestals.
    (d) As well as the installation, small hand-held waves were handed to participants as they arrived and used as an entry point to engage individually with participants on their background, expectations from the workshop and perspectives on sustainability challenges facing coasts and seas before and after the workshop.
    (e) A QR code that linked to the CAW website was sand-blasted onto the bottom surface of hand-held waves to promote longer-term connection to the project.
(4) The main body of the workshop consisted of a series of video presentations to represent each of the 5Ps and each video was immediately followed by a facilitated discussion on how the video linked to and juxtaposed with individual perceptions to the challenges of coastal and marine sustainability.
(5) During both workshops, a graphic artist made a recording of the conversations by visually articulating how the discussions and conversations were formed, and highlighting those aspects of coastal and marine sustainability participants considered most important and urgent, as well as mechanisms for learning (**Figure 5**).

From the CaW side, the intent of workshop discussion was to explore how an art-science partnership could engage with non-scientist audiences to recognize and emphasize what is perceived by the science community as a critical state of the world's oceans (IPCC, 2019) through a transdisciplinary approach. However, from the workshop participants the discussion revolved around how collaborative efforts such as CaW should work internally to extend beyond interdisciplinarity and achieve a transdisciplinary approach, as well as the need to be flexible and agile in terms of project goals and objectives. The messaging also from the workshops elucidated an increasing desire amongst researchers from more artistic disciplines for optimistic and empowering efforts that unite communities and populations rather than fear-driven efforts that have a more dividing response. In general, it became apparent that whilst natural sciences are comfortable with the drive of the UN Agenda 2030 and the SDGs, there is strong criticism of these initiatives from other disciplines and a perceived lack of societal focus in implementation (Liverman, 2018; Swain, 2018). Outcomes from discussions suggested that:

(1) Trying to set a broader context of SDGs to meet the composition of the audience had the unintended outcome of losing clarity around the place of sciences in the context of the art.
(2) Achieving a balance of synergies and trade-offs between environmental change and impacts on society is challenging.
(3) There is a need to lead with the requirement for a transdisciplinary approach to justify and validate a wider context rather than a focus on specifics (e.g., SDG14).
(4) There are currently weak procedures to assess the art-science collaborative process to evaluate the impact of transdisciplinarity endeavors and their behavioral influences on diverse communities of interest.

Overall, there was validation of the proof of concept in that participants were strongly encouraging that the blending of science and art used by the CaW project presented considerable opportunity to lead to more meaningful engagement across different communities, but the collaboration needed to be widened to ensure transdisciplinarity.

Engagement and Impact

The overall goal of CaW has adapted into the development of a process of engagement and collaboration that enables moving beyond accounting for impacts on coastal and ocean systems to instead address concerns around closing knowledge gaps to specifically empower those who are often left out of the management and usage conversation for a variety of reasons. CaW has therefore been influenced by the desire to contribute to providing new tactile and other sensory experiences that connect recognized and disenfranchised stakeholders to ocean and coastal spaces, specifically shaping that experience with, and for, those likely to be impacted by changes to the system.

With each iteration, CaW has demonstrated learning within the project team across social, ecological, and physical aspects of the oceans while providing space for both cultural identity and technological and social innovation. This approach has allowed the CaW project to move beyond a 'service mentality' where science and art products are produced in isolation into the development of an integrated collaboration space that can demonstrate the power and synergies between these disciplines. A critical review of this learning gleaned from the workshops has provided an opportunity for the evaluation of the potential knowledge generation of CaW using both the framework discussed in **Figure 1** as well as the ontological logic of interdisciplinarity previously presented (Barry et al., 2008; Born and Barry, 2010).

Barry et al. (2008)'s ontological logic enables the exploration of how CaW processes of scientific and technological production; in the process of creating the glass waves, for example, altering ways of thinking about the relationships between science and art and

FIGURE 5 | A graphical recording of the CaW interactive workshop at the Art in the Anthropocene Conference 2019 that captured conversations and observations made by attendees. Graphic Artist: Eimear McNally.

the objects they produce. A co-benefit from a shift in behavioral responses across different sections of society toward action for more sustainable oceans and coasts would be to reduce gaps in their viewpoint of the UN Agenda 2030 and the SDGs. To date, CaW's engagement has been largely limited to inherently science-art audiences. This has been critical to both message development and anchoring of the work in local contexts. However, future events are being planned to target a range of different audiences. This will provide a greater opportunity to increase accessibility of outputs to different stakeholder groups and audiences allowing more avenues for impact across scales. Increased engagement is expected to strengthen the evidence and co-designed elements of CaW outcomes.

Technology and artistic innovation have played a large role in CaW's development as the project's message has matured from pathways to sustainability toward a vision with a stronger social justice influence. This has included the development of a website[2] and use of social media to promote art-science messaging. The inclusion of audio, especially the voices of coastal inhabitants, has provided an additional avenue to anchor the work with personal experiences that describe different aspects of human connection to ocean and coastal spaces. In retrospect, this anchoring has provided profound influence for the project's own transformation by allowing actors in society to describe the types of knowledge gaps that exist within their own decision making and spheres of influence.

CHALLENGES AND OPPORTUNITIES OF COLLABORATIONS IN THE ANTHROPOCENE

While case studies like CaW can demonstrate the importance of not only transdisciplinary approaches for knowledge generation, they also raise many questions around who is generating that knowledge, and how it is utilized. As social justice becomes a more systemic consideration for the SDGs (Freistein and Mahlert, 2016; Scoones et al., 2020), questions around power and influence over decision making become more pertinent (Bexell and Jönsson, 2017; Fukuda-Parr and McNeill, 2019). A series of multiple, often contested, pathways for guiding societies toward sustainability have been identified with controversies emerging between weak and strong sustainability (Dietz and Neumayer, 2007; Neumann et al., 2017), between techno-centrism and eco-centrism (Audet, 2014), between adaptation and transformation (Dow et al., 2013) and between reformist and revolutionary positions (Geels, 2011; Geels et al., 2015). This contested space, all argued from a position of evidential strength, highlights the need for a more negotiated process that can develop clear bargained objectives where, both at individual and collective scales, the many technical and/or technocratic solutions that are presented by disciplines can be evaluated and re-evaluated to determine a positive way forward.

Art-science collaborations offer a way to structure the discussions that arise at each decision point on the sustainability route. Art offers a way of creating a platform that allows different perspectives and different conversations to take place in order to negotiate or bargain which pathway or which approach society may want to adopt in that journey. In this way, the model presented in **Figure 1A** becomes a series of feedback systems for potential persuasion as well as knowledge generation (**Figure 6**) that is underpinned by the constructs in **Figure 1B**. The feedback loop provides a mechanism for the needs of society to influence the knowledge that is being generated by art, science and technology or any combination of the three. Therefore, this re-imagined space creates a strong opportunity to fully engage with issues raised under a social justice lens in the future as well as provide an avenue for society to actively define knowledge needs. Acknowledging that collective action and behavioral change, at all scales, is strongly dependent on networks and flows of information between individuals and groups and the relationships and patterns of reciprocity and

[2]www.catchingawave.org

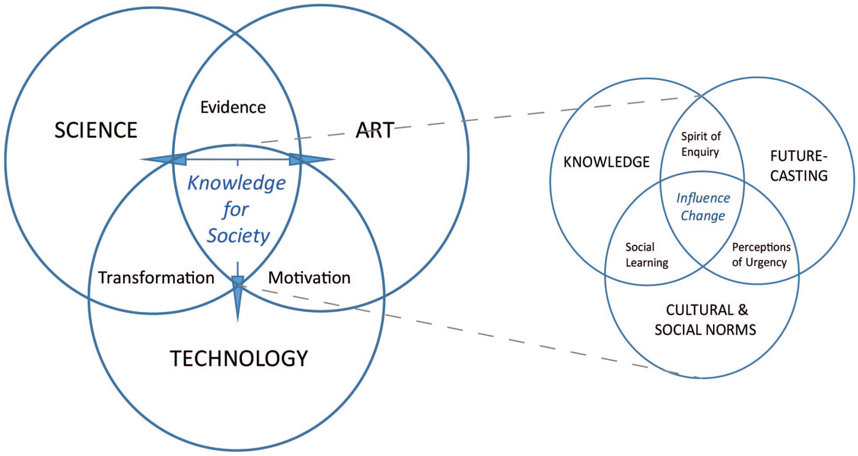

FIGURE 6 | A model of knowledge generation that is responsive to the needs of society and allows reciprocity and exchange between and within disciplines.

exchange, rupturing the engrained *status quo* of divisions across and between academia and society offers solutions spaces rather than dictates destinations.

While the literature and concepts discussed in this paper, as well as the case study, demonstrate transdisciplinary benefits, it must also be recognized that there are methodological and collaborative challenges necessary for such endeavors. This reality has stimulated critical reflection on practice and limitations in traditional disciplinary evaluation methods (e.g., Muller et al., 2015; van Mierlo and Beers, 2018) but also allowed space from reframing art-science intersections as 'shared encounters with politics and environmental change' (Gabrys and Yusoff, 2012). While there are two central themes that resonate within current art-science collaborative practice: (i) the ability to engage diverse publics (Gabrys and Yusoff, 2012; Lesen et al., 2016) and (ii) the ability to 'do' social, cultural and political work (Gibbs, 2014; Galafassi et al., 2018), there is evidence that expectations of artists and scientists may differ as a consequence of disparate training, methods, values, vocabulary, funding, and income (Lesen et al., 2016). If art-science collaborations are visualized on a spectrum, at the 'service mentality' end artists might take inspiration from science but not work directly with scientists, and likewise there might be scientists making art without direct contact with artists. At the other end of the continuum, integrated partnerships between artists and scientists have been gaining in popularity as an intellectual practice, however, disciplinary integration remains a difficult obstacle to overcome.

Nevertheless, within the sustainability and climate change arena, increasingly framed within the concept of the Anthropocene (Crutzen, 2006), integrated, co-designed and co-produced, challenge-led collaborations can provide the innovation needed to allow the visualization and realization of solutions and pathways to sustainability become more reachable from a local to global scale across social and political spectra (Reed and Abernethy, 2018). As Biermann et al. (2016) state 'The Anthropocene is now being used as a conceptual frame by different communities and in a variety of contexts to understand the evolving human–environment relationship.' The authors go on to state that '. . .the Anthropocene can be a useful conceptual frame only when it is viewed from a cross-scalar perspective that takes into account developments at local, regional and global levels, variant connections among these levels and issue domains, as well as societal inequality and injustice' (Biermann et al., 2016). The power of the Anthropocene concept, therefore, is in examining and amplifying (i) complex normative understanding (making pervasive inequalities more visible); and (ii) novel directions for better governance, from local to global (Biermann et al., 2016) including increasing centrality of actors from the whole myriad of social structures. This contextualized, localized and social understanding of the Anthropocene, sensitive to global inequalities and disparities, can contribute to new insights into global and local interconnectivities relevant to the delivery of the SDGs and other international conventions (e.g., the New Urban Agenda, Paris-COP21, and the Convention on Biological Diversity).

CONCLUSION

There is precedent for urging against modernist metaphors of 'building bridges' across disciplinary divides and instead for 'plunging into the river together, rather than attempting to bridge it' (Head, 2011) that supports the notion that insights from both the arts and sciences will be needed to overcome maladaptive practices by practitioners and society alike common in the Anthropocene. Art-science collaborations aim to transcend practices that compartmentalize knowledge, instead catalyzing innovations by cross-pollinating disciplinary processes and products (Leimbach and Armstrong, 2018). While art-science collaboration is often touted as 'transformative' resulting in changes in perspectives or insight by facilitating engagement with the public or with stakeholders and subjects of science, mechanisms that begin to measure this impact-to-influence remain challenging (105). Quantitative methods (visitor numbers, citations, etc.) do not provide the data needed to determine the value and benefit of aesthetic engagement, while conventional qualitative evaluations are insufficient because they do not assess value beyond their disciplinary value structures. This research space opens several potential avenues of novel investigation in the future.

Studies have recognized that environmental issues and societies responses to them are in themselves a competitive space (Tiller et al., 2019). The process of understanding the need for significant systemic changes in practices, informed by scientific analysis of trends, acknowledging local knowledge and ways of knowing, and taking stock of social-ecological system constraints and opportunities for transformation is critical to the approach described in this paper. The multifaceted challenges of coastal and ocean sustainability cannot be addressed by science alone. While it is often easier to describe the problem rather than to agree on the actions that need to be taken in specific contexts to address those risks, the demand for innovative research and practices that 'think outside the box' – with new modalities of transdisciplinary action research that complement traditional disciplinary research is growing rapidly. There is an urgent need for new means of representation to convey the complexity of environmental change, and a growing recognition of the limited ability of science alone to influence policy change. Sustainability and climate science are the latest to acknowledge the urgency to rupture this *status quo* in order to enable action.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Written informed consent was obtained from the relevant individuals for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

SP: conceptualization, methodology, writing – original draft preparation, and writing – review and editing. ML: conceptualization, methodology, writing – original draft preparation, and writing – review and editing. HW: conceptualization, methodology, project administration, visualization, and writing – review and editing. LR and KT: conceptualization, funding acquisition, investigation, and methodology. MI: conceptualization and writing – review and editing. JM: data curation, formal analysis, investigation, and visualization.

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PERSPECTIVE
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A Scientist's Guide for Engaging in Policy in the United States

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Scientific research and expertise play a critical role in informing legislative decisions and guiding effective policy. However, significant communication gaps persist between scientists and policymakers. While interest in science policy among researchers has substantially increased in recent decades, traditional academic and research careers rarely provide formal training or exposure to the inner workings of government, public policy, or communicating scientific findings to broad audiences. Here, we offer 10 practical steps for scientists who want to engage in science policy efforts, with a focus on state and federal policy in the United States. We first include a primer to government structure and tailoring science communication for a policymaker audience. We then provide action-oriented steps that focus on arranging and successfully navigating meetings with government officials. Finally, we suggest structural steps in academia that would provide resources and support for students, researchers, and faculty who are interested in policy. We offer our perspective, as early-career marine scientists who have participated in policy discussions at state and federal levels and through the American Geophysical Union's "Voices for Science" program. This guide offers potential pathways for engagement in science policy, and provides researchers with tangible actions to effectively reach stakeholders. Lastly, we hope to activate further conversations on best practices for policy engagement, particularly for researchers interested in careers at the science policy interface.

Keywords: science policy, government relations, policy engagement, science advocacy, United States policy

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INTRODUCTION

Scientists are increasingly motivated to engage in science policy, either through communicating scientific results to policymakers or science-based advocacy (Baron, 2016; Hutchings and Stenseth, 2016). Many scientists believe they should engage with policymakers and play a role in shaping public policy, especially when policy issues or legislation directly relate to science (e.g., stem cell research; Besley and Nisbet, 2013). Policymakers and media outlets often rely on the expertise of scientists for interviews, testifying in congressional hearings, or addressing the general public on policy issues related to their research. However, while interest in policy has grown within the scientific community, large gaps in communication and engagement persist between scientists and policymakers.

Previous studies have reviewed the numerous barriers that contribute to the science-policy divide (e.g., Bertuol-Garcia et al., 2018). These barriers include, but are not limited to, scientists' questioning their own competence or expertise, believing their research is too complicated, narrowly-focused, and perhaps not relevant to larger policy discussions (Poliakoff and Webb, 2007; Singh et al., 2014). Some scientists are reluctant to engage in policy efforts because they are concerned about the politicization of science and blurring lines between acting as a knowledge broker versus an advocate (Weingart, 1999; Miller, 2009; Gluckman, 2014). Scientists and policymakers often have different motivations, goals, and objectives, which may limit collaboration or engagement between sectors. Researchers are also time limited and academic institutions often do not reward community related outreach activities (Singh et al., 2019), which may limit scientists' abilities to engage in policy outreach. Lastly, traditional academic pathways provide little training in science policy, communication, disseminating research to broad audiences, or using science to inform policy. Therefore, this lack of training on how to effectively engage in policy may be a barrier that limits scientists' participation. To bridge this gap, we focus specifically on how scientists can engage in policy, rather than if, when, or why scientists should engage.

Our primary objective is to create a guide for scientists who are interested in participating in policy but lack the training, practice, or resources to begin. The secondary objective is to begin a larger conversation about science policy engagement and best practices for scientists to take part in policy actions that relate to their expertise or field of study. We recognize that there are many pathways to engage in science policy, and the most effective actions may differ between countries with different governments and processes for enacting legislation. We specifically focus on 10 tangible actions to engage in science policy at local and federal levels in the United States and provide pertinent resources to do so. While we focus on U.S. policy, many of the steps are broadly relevant and we hope this framework will be adapted and edited to address science policy initiatives at different scales (local, regional, national, international).

STEP 1: LEARN HOW SCIENCE POLICY IS ENACTED

Science policy is an extensive international field encompassing collaborations between government agencies and non-government organizations and research scientists from various sectors (Etsy and Ivanova, 2002; Petes and Meyer, 2018). Here, we primarily focus on the subsection of science policy within the U.S. federal legislative branch, i.e., the U.S. House of Representatives and the U.S. Senate, as this offers one practical and specific avenue for engagement. In the United States, the House has 435 representatives who represent their congressional district for 2-year terms and the Senate consists of 100 senators (two per state) elected for 6-year terms. Any of these 535 members may propose or introduce a bill. The member of Congress that proposes a bill becomes the primary "sponsor," but an unlimited number of fellow members can lend support by becoming "cosponsors". Bills go through many steps prior to becoming law (**Figure 1**). After proposal, bills are sent to committees (20 in the House, 16 in the Senate) and then subcommittees, with numerous opportunities for revisions and votes. Due to the many steps in this complex process, most introduced bills do not become law. For example, in the 115th congress (January 2017–January 2019), only 867 of 13,556 bills and resolutions were brought to a vote. In total, only 3% of bills and 6% of resolutions were adopted.

To engage in the legislative process, scientists can research and focus on actions within committees and subcommittees of broad relevance to science (**Figure 2**). For example, marine biologists may be interested in tracking legislation and activity of the Senate subcommittee on Fisheries, Water, and Wildlife or the House subcommittee on Water, Oceans, and Wildlife. To track votes, hearings, and mark-ups within these subcommittees, researchers can sign up for email alerts on govtrack.us. See the **Supplementary Material** for additional resources for tracking science policy news.

Typically, bills are only brought to public attention at the time of Senate or House votes, which is toward the end of the legislative process. By tracking committee action, informed scientists can engage with legislators and show support or opposition for a bill throughout the process. Importantly, policymakers will sometimes publicly solicit information, giving scientists the opportunity to offer input on a bill. Tracking a bill through congress can thus provide scientists with a more direct impact on its success or failure. Scientists can also engage with their senators or representatives by asking for specific action (e.g., cosponsoring or supporting a bill) on legislation. See "Step 4" for details on effective communication with members of Congress. Although these steps are specific to science policy within the U.S. federal government, we note this strategy of investigating pathways of legislation is generally useful for initiating engagement in science policy.

STEP 2: UNDERSTAND HOW SCIENCE IS FUNDED

To better advocate for continued government-supported research, scientists should learn how federal agencies that support their research (e.g., National Science Foundation, National Institutes of Health, the Department of Defense) are funded. Briefly, the federal budget is divided into mandatory expenses (e.g., Social Security, Medicare, Medicaid, interest on the national debt) and discretionary spending (**Figure 3**). Discretionary spending is further divided into defense and non-defense spending. Scientific research is primarily sponsored by the latter, in non-defense discretionary (NDD) spending, which accounts for approximately 15% of the total federal budget. NDD funding, which encompasses "general science and basic research" and "space and other technology" also includes many other areas (e.g., education, veterans' benefits, health, transportation; **Figure 3**). General science is thus only a small portion of this NDD spending. For example, in fiscal year 2018, spending in general science, basic research, and space technology totaled $31.4 billion or 4.9% of NDD funding ($638.9 billion) and 0.76% of total federal spending ($4.1 trillion).

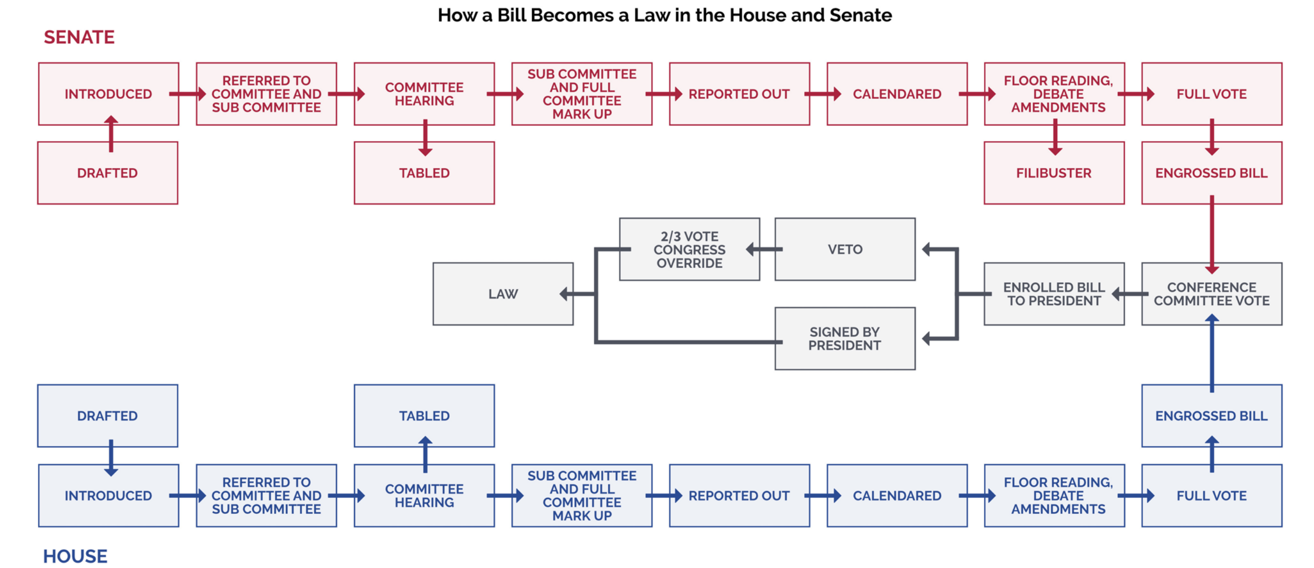

FIGURE 1 | Flow chart of legislation in the U.S. House of Representatives (blue) and Senate (red), highlighting the numerous steps a potential bill takes before being signed into law. Understanding these pathways allows scientists to engage throughout the bill's lifetime rather than toward the end of the legislative process.

Each year Congress must pass a suite of appropriations bills that set these NDD spending outcomes. Generally, this process occurs annually in Spring, but in recent years, the budget process has been extended with continuing resolutions, or temporary measures that provide short-term funding to avoid a government shutdown. Due to this dynamic nature of appropriations decisions, we recommend subscribing to newsletter services or tracking appropriations committees on govtrack.us directly for notifications on important actions. Other organizations like the National Oceanic and Atmospheric Administration (NOAA) and the American Institute of Physics (AIP) also offer useful, interactive budget trackers on their websites (see **Supplementary Material**). Before these decisions are made, scientists can contact their legislators and advocate for increased NDD spending. This is especially impactful if your house representative and/or senators are members of the House or Senate appropriations committees. In addition to advocating general science funding, scientists can advocate for agency-specific funding increases. Generally, agencies require at least ∼3–5% annual funding increases to account for inflation and growth. This target therefore provides a baseline for requests to policymakers when discussing appropriations goals.

STEP 3: PRACTICE COMMUNICATION SKILLS

Scientists lacking experience communicating their research in plain language to a policymaker audience should seek opportunities to develop their communication skills. Many universities have communication offices that connect students and employees with various local and regional news organizations, provide workshops on communicating research, and offer various outreach programs. While summarizing scientific communication opportunities is outside the scope of our objectives, we emphasize that developing communication skills to broad audiences is essential for effective science policy discussions.

Specifically, we recommend creating a "one-page document" or "one-pager" when communicating with policymakers. These documents are brief summaries of scientific research and relevant requests. They are useful for building relationships with congressional staffers and help prioritize conversations with policymakers. Effective one-pagers tell a concise story by offering an explanation of a research topic, establishing the importance of the topic, its relevance to policy at the local, state, or federal level, and clearly outlining the action (if any) you would like the office to take (see section "Step 5: Schedule a Meeting With Policymakers" for more details). See **Supplementary Material** for more details on crafting an effective one-pager.

For graduate students or early career researchers who are motivated to gain hands-on experience communicating with policymakers and are considering careers in science policy, there are numerous science policy fellowships. See the **Supplementary Material** for a compiled list of fellowships that provide short-term (typically 12 months) appointments in various facets of science policy and communication.

STEP 4: FIND YOUR ELECTED OFFICIALS

Communicating with appropriate government officials and policymakers, relative to the scope and focus of your research expertise, is necessary for effective participation in science policy. If your topic of interest relates specifically to your

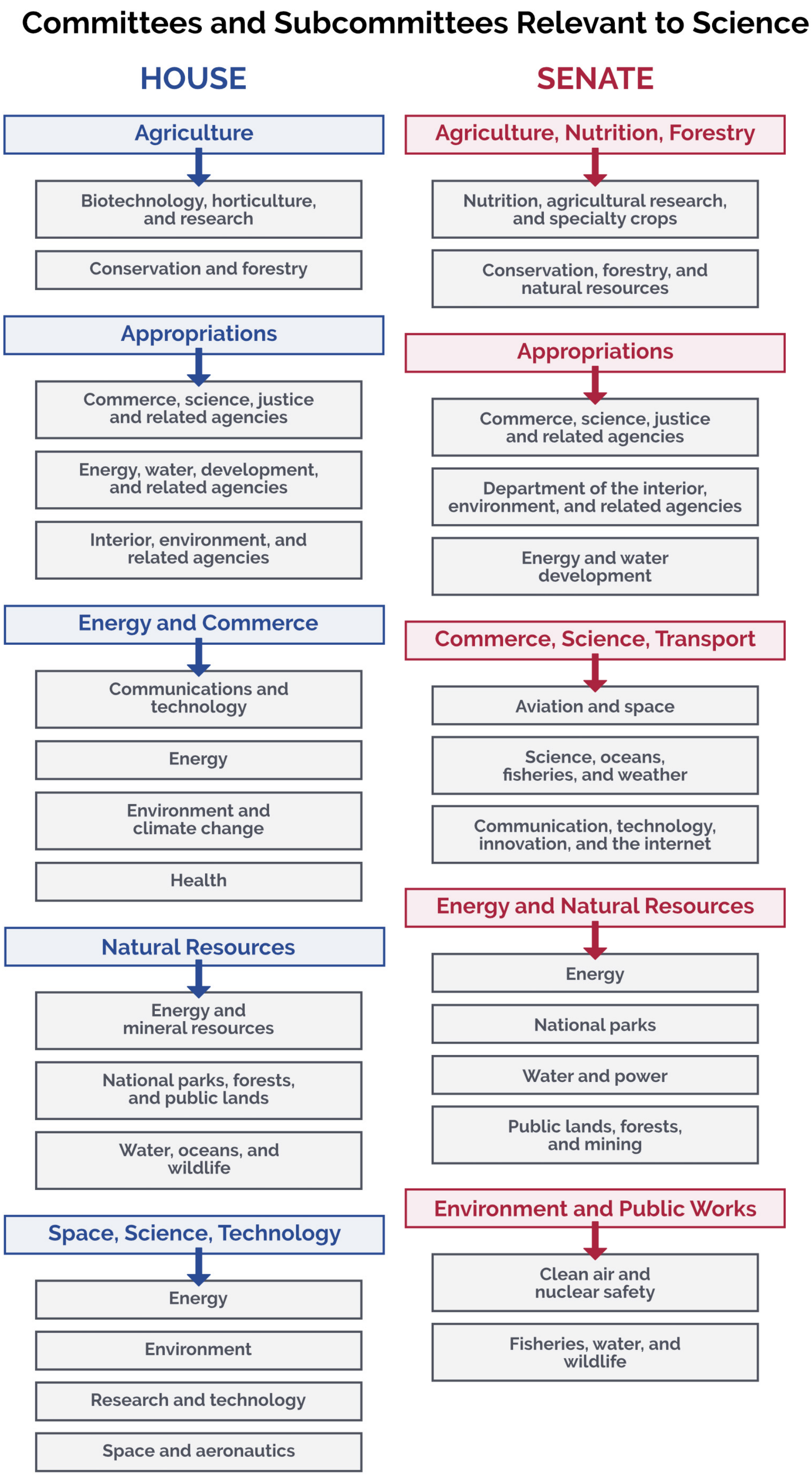

FIGURE 2 | Current 2019 standing committees in the U.S. House of Representatives (blue) and Senate (red) with the highest relevance to science and science policy. Within each committee, numerous subcommittees exist with narrower scopes within science and engineering. We recommend by identifying one to three relevant subcommittees and tracking their actions directly on govtrack.us.

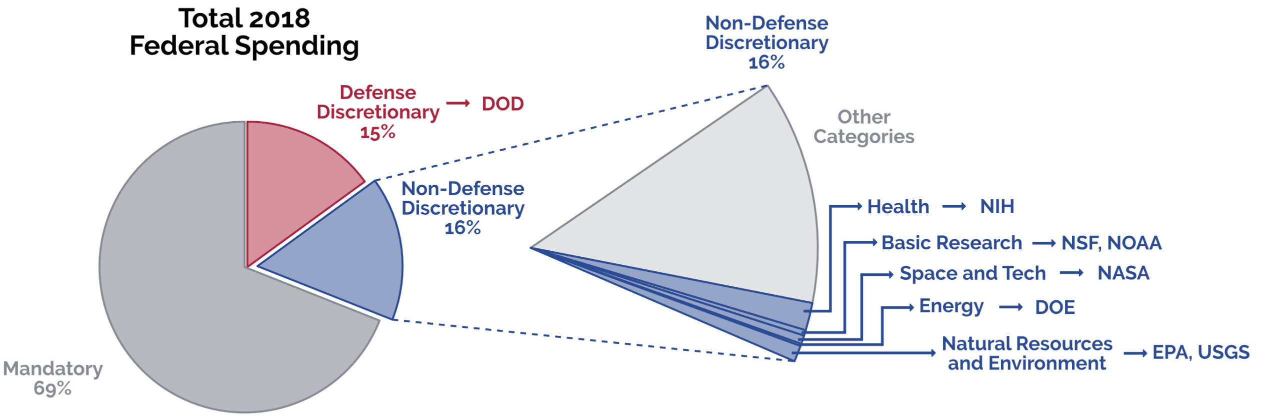

FIGURE 3 | Proportions of fiscal year 2018 federal spending, highlighting scientific research and agencies nested within the overall budget. Government spending is broadly divided between mandatory (gray) and discretionary expenses (blue and red). Mandatory expenses are largely determined by the White House Office of Management and Budget (OMB) and are inflexible. Appropriations bills are required to set discretionary spending. Non-defense discretionary spending (blue) is more flexible and supports a large portion of scientific research within the United States and is decided by appropriations bills in Congress. Arrows indicate some of the agencies that are funded through each category; Department of Defense (DOD), National Institute of Health (NIH), National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), United States Geologic Survey (USGC).

congressional district, identify your representative[1] and senator[2]. Using personal congressional websites and govtrack.us, find their committee assignments and track bills that they have sponsored and co-sponsored to examine their positions and involvement on science related issues. Outside Congress, research agencies and government officials (e.g., staff in the mayor's office, city or town council members) in the community, especially when there are local policy issues relevant to your science expertise. For example, if you are interested in coastal resilience to climate change, research whether your city or state has a climate action plan.

STEP 5: SCHEDULE A MEETING WITH POLICYMAKERS

For scientists beginning to engage in policy, a streamlined way to navigate congressional meetings is to attend an official congressional visit day through an organization. These are days dedicated to specific issues on Capitol Hill (e.g., Climate Science Day, Ocean Week, or Geosciences Congressional Visits Day). Some scientific organizations (e.g., the American Geophysical Union, the American Institute of Biological Sciences) organize and provide funding for scientists to participate in these science advocacy days on Capitol Hill.

If attending a congressional visit day is not possible, universities often have a government relations office that can facilitate meetings with local policymakers. Partnering with scientific organizations or university offices that regularly communicate with congressional offices will lower the entry barrier to engage in science policy and will provide support on how to successfully navigate congressional meetings. However, if these avenues are not available, many legislators have "Request a Meeting" tabs on their websites, which include contact information for direct requests to meet with staff members. Be aware that the process of scheduling a meeting may take several months and is dependent on the congressional calendar.

Prior to scheduling, research the policymaker of interest. Visit their official website and govtrack.us (see Step 1) to identify which bills the legislator has sponsored and co-sponsored. Research their prior support for science and the specific request you are planning to discuss. Having clear, realistic objectives is crucial for effective meetings. Congressional staffers are extremely time-limited and will inquire about the purpose of your visit prior to scheduling a meeting.

STEP 6: NAVIGATE MEETINGS WITH POLICYMAKERS

Congressional staffers meet daily with many people, so at the beginning of the meeting introduce yourself clearly and try to make personal and local connections. If applicable, thank the office for a recent action, such as sponsoring a bill related to your topic of interest. If discussing your research, ensure that you relate it to a broader topic of relevance to the district and policymaker, and share how government funding has directly supported your research. Be prepared with "asks," or tangible actions for the office. Asks can be general (e.g., advocating for increased science funding; see section "Step 1: Learn How Science Policy Is Enacted") or specific (e.g., related to a particular issue or piece of legislation). If appropriate, ask the legislator to consider signing, cosponsoring, or sponsoring a piece of legislation, or consider drafting new legislation.

Although it is recommended you are prepared with concrete "asks" for the office, leave room for a two-way dialog with the staff

[1] www.whoismyrepresentative.com
[2] https://www.senate.gov/senators/

member. Many meetings are dominated by the visitors speaking, but listening is critical for building a relationship. Ask about science-related issues that are most important to their office and how your expertise may be helpful to the staffer.

At the end of the meeting, leave your contact information and one pager with the office (see Step 3). Within a few days of your meeting, follow up with an email to thank the office. At this time, it is useful to attach an electronic version of the one pager and a recent journal or news article relevant to your discussion.

STEP 7: ENGAGE IN SCIENCE POLICY AT CONFERENCES

Conferences are excellent opportunities to engage with policymakers, managers, and scientists with common interests on bridging the science policy divide. Meetings, such as those organized by the National Council for Science and the Environment and the National Marine Sanctuary foundation, are policy specific. Further, certain universities send delegations to international policy meetings and/or can provide financial support for students and researchers to attend policy meetings. However, for some researchers, especially students, attending a policy conference may not be feasible without support of their advisor. Advisors may be unwilling or unable to provide support for students to attend workshops or conferences that do not directly support their research. If financial constraints are the primary barrier, consider advocating for small departmental travel grants to cover the costs (see Step 9 for other ideas on increasing institutional support).

If attending a policy conference is not possible, take advantage of policy-related opportunities at larger research-focused conferences. There are often sessions, town halls, and workshops dedicated to education, management, and policy. Certain conferences (e.g., Ocean Sciences Meeting, American Geophysical Union Meetings) also allow researchers to submit two abstracts if one focuses on education or policy. Taking advantage of these opportunities (see **Supplementary Material** for further details) enriches both the individual scientists and the university, as it demonstrates active connections between research, policy, and communicating science to a larger community.

STEP 8: PUBLISH POLICY BRIEFS AND OPEN-ACCESS

There are multiple barriers to disseminating scientific results to policymakers. Scientists typically present their research findings at conferences and through publication in academic journals. Managers and policymakers often lack access to scientific journal articles, which contributes to the science policy divide (Edwards, 2004). To make articles more accessible to the general public, scientists are increasingly publishing “open-access” papers, which are free to all readers. However, authors are responsible for covering the additional fees associated with publishing open-access articles, which are prohibitive for some researchers. Further, even when publications are available to policymakers, papers may be written in a technical manner, rendering the findings less accessible to many policymakers and management agencies.

In addition to publishing in open-access journals, scientists can make their research more accessible to policymakers by publishing a “plain-language summary” alongside manuscripts that summarize the findings for a general audience. Some journals (e.g., all journals by the American Geophysical Union) provide this option to authors. Another example of this approach is from intergovernmental organizations, such as the Intergovernmental Panel on Climate Change (IPCC), which publishes both a long technical report on climate change science and a short policy brief that highlights the major outcomes of the technical report. Scientists can seek out journals that have plain-language summaries or suggest them to editors in other journals. They can also write policy briefs or plain-language summaries to accompany each publication and send those summaries to policymakers, post them to social media accounts, or include them on personal and/or lab websites.

STEP 9: BRING SCIENCE POLICY TO YOUR INSTITUTION

The outlined steps have thus far primarily focused on individual actions, but engaging peers from your university or scientific community can be impactful for effective policy discussions. Universities can play an important role in building programs and courses that provide students with experiences that link science, policy, and society (Petes and Meyer, 2018). At the departmental level, advocate for inviting policy-focused individuals to departmental seminars. If there are alumni from your institution that have entered policy careers, invite them for a seminar or panel discussion. It may also be possible to invite a staffer from a local congressional or state senator’s office for a special seminar on a timely policy issue. Reach out to the government relations office at your university to inquire about this possibility. Through their office, it may be possible to invite local policy makers and their staff to your lab, or department, for a tour or special seminar.

To build a science policy community at your institution, consider founding or joining a club. The club can provide a means to host speakers and science policy events at your university. For example, when relevant legislation is introduced, host a postcard night or town hall discussion. The club can also organize group trips to Capitol Hill or the local office of senators or representatives. These collective actions can bridge science and policy and lower the barrier for early career researchers to engage in policy efforts.

Lastly, these actions are not possible without institutional support. It is critical that faculty advisors, departments, and universities support early career researchers interested in policy engagement. Professors also need institutional support to engage in policy initiatives without concern of stalling progress toward research, publications, tenure, or promotion. To bridge the divide between research and policy, these efforts should be viewed as a complement to research and outreach efforts.

STEP 10: ACTIVATE THE COMMUNITY

From a science policy perspective, researchers can use outreach efforts to engage on issues that are particularly relevant to a given community (e.g., climate resiliency, plastic pollution, water quality). Elected officials are chosen to represent their constituents. When constituents are passionate and particularly vocal about an issue, legislators are more likely to pay attention. Through actions like creating citizen science projects, we can engage the public in science, increase awareness about certain issues (Bonney et al., 2016), and potentially change attitudes or behaviors. Ultimately, public opinion is important for shaping policy outcomes and building support for legislation.

Scientists interested in policy should also attend community events, even when they are unrelated to their policy topics of interest. For example, find the congressional calendar to see when policymakers are home in their district, and attend city council or town hall meetings. Attending community events will provide perspective on issues community members are most engaged and passionate about. Outreach ultimately benefits scientists, institutions, and the surrounding community. Strengthening connections between research and local communities can help build public trust in science and support for federally funded science programs from the general public. While these efforts are more indirect and have a longer-term focus, building relationships in the community is an effective strategy for gaining awareness and eventual support for specific policy actions.

CONCLUSION

As scientists are increasingly inclined to engage with policymakers or pursue policy-related career paths (Miller, 2009; Petes and Meyer, 2018), guidance is needed on how scientists can effectively offer knowledge and expertise to guide policy. We highlighted 10 tangible and actionable steps that we hope will provide guidance for researchers on how to begin. While we outlined discrete steps, we emphasize that bridging the gaps between science and policy requires continued engagement that goes well beyond these actions. Continued engagement requires building relationships and trust between the scientific community and different stakeholders, which is built over time, with considerable effort and collaboration (Gluckman, 2014).

We focused on federal policy in the United States, reflecting our personal experiences engaging in science policy. However, the actions we proposed centered on learning how policy is enacted, how to communicate and meet with policymakers, and make research findings more accessible. These principles are broadly applicable to global efforts, as they create a foundation for researchers to engage with the policy community. While the details of how to engage likely varies between countries with different government structures, we hope this guide provides a useful framework that can be adapted and modified for researchers at the science policy interface outside of the United States.

AUTHOR CONTRIBUTIONS

EH developed the concept for this manuscript and contributed to the development of each section. AP designed figures and contributed to the development of each section. Writing and editing the manuscript was equally divided by EH and AP.

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SUPPLEMENTARY MATERIAL

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Messaging on Slow Impacts: Applying Lessons Learned from Climate Change Communication to Catalyze and Improve Marine Nutrient Communication

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Building publics' understanding about human-environmental causes and impacts of nutrient pollution is difficult due to the diverse sources and, at times, extended timescales of increasing inputs, consequences to ecosystems, and recovery after remediation. Communicating environmental problems with "slow impacts" has long been a challenge for scientists, public health officials, and science communicators, as the time delay for subsequent consequences to become evident dilutes the sense of urgency to act. Fortunately, scientific research and practice in the field of climate change communication has begun to identify best practices to address these challenges. Climate change demonstrates a delay between environmental stressor and impact, and recommended practices for climate change communication illustrate how to explain and motivate action around this complex environmental problem. Climate change communication research provides scientific understanding of how people evaluate risk and scientific information about climate change. We used a qualitative coding approach to review the science communication and climate change communication literature to identify approaches that could be used for nutrients and how they could be applied. Recognizing the differences between climate change and impacts of nutrient pollution, we also explore how environmental problems with delayed impacts demand nuanced strategies for effective communication and public engagement. Applying generalizable approaches to successfully communicate the slow impacts related to nutrient pollution across geographic contexts will help build publics' understanding and urgency to act on comprehensive management of nutrient pollution, thereby increasing protection of coastal and marine environments.

Keywords: climate change communication, nutrient management, science communication, nutrient communication, science of science communication

INTRODUCTION

There is a large disparity between the scientific and public understanding of the consequences of nutrient pollution. Intentional engagement with localized publics on the significance of the problems created by nutrient pollution and the need for collective behavioral change is essential for achieving management goals. To date, national, regional, and local policies to manage nutrients are a start in translating science for public benefit, but current policies and public engagement do not match the scale of the nutrient pollution challenge. Given the scarcity of this engagement, there is a need for more effective science communication about nutrient pollution and its impacts. We use "nutrient communication" to refer to this needed increase in translation of science and engagement with publics to address nutrient pollution.

Nutrient pollution is increasingly understood in terms of ecological and social impacts, alongside the identification of sources and potential management actions. The primary nutrients of concern are reactive nitrogen and phosphorus. These nutrients occur naturally throughout the biosphere, but the levels of both have been increased significantly through various human activities to the point of polluting our environment. The fact that healthy ecosystems require these nutrients in certain quantities, but they become pollutants at higher levels, makes it difficult to determine and communicate the point at which these nutrients become pollutants (Nixon, 1993; Merrill et al., 2018). Additionally, the combination of point sources, such as concentrated animal feeding operations, and nonpoint sources, such as septic systems and fertilizer run-off from row-crop agriculture, make nutrient pollution difficult to manage. Nonpoint sources are the extensive inputs of nutrients without a single "point" of origin. This nonpoint nature makes nutrients more difficult to manage, as all the diffuse small sources must be managed among many individual actors, often without legal mandate, rather than addressing a singular potent polluting site (EPA, 2020b). The U.S. EPA (2020b) reports that nonpoint source pollution is the main remaining cause of impaired water quality. While addressing nutrient pollution across the range of sources and impaired waterbodies is important, this article focuses specifically on communicating the impacts of nonpoint source nutrient pollution on coastal water quality.

In most coastal waters, availability of reactive nitrogen is most important because it limits primary production more than phosphorus does (Howarth and Marino, 2006). Excess reactive nitrogen can cause heightened algal production and biomass, harmful algal blooms, accelerated coral reef decline (Zaneveld et al., 2016), seagrass loss due to shading, and degradation of fish and other aquatic communities due to low oxygen. Point sources of nutrients include wastewater treatment facilities, stormwater outfalls, and concentrated animal feeding operations (Carpenter et al., 1998). These sources are managed as identifiable "points" of nutrient input, with certain amounts of nutrient inputs permitted. Important nonpoint nitrogen inputs include septic systems (EPA, 1996), agricultural runoff (Van Meter et al., 2016) and atmospheric deposition (Carpenter et al., 1998). An added difficulty in nutrient management is that impacts may occur far downstream from sources, may take an extended period of time to fully manifest, and may persist long after sources have been eliminated (Van Meter et al., 2016; Merrill et al., 2020). Transit time for nutrients from sources to receiving waters can vary from hours to decades, in the latter case usually when transport via groundwater is involved (Van Meter et al., 2018). Additionally, even once reaching a larger waterbody, the impact of the nutrients on the ecology of the system takes time and can be cumulative (Verdonschot et al., 2013). In these cases of delayed impact, the nutrient levels in waterbodies and consequential eutrophication (Pérez-Ruzafa et al., 2019) can reflect nutrient inputs that preceded implementation of nutrient management, delaying recovery of ecosystem functioning (Carstensen et al., 2011). This legacy impact makes it difficult to understand effects of nutrient management interventions and to communicate the importance of such interventions. To address the challenges of aquatic nutrient pollution, research has found that the most effective management plans comprehensively address all nutrient sources (Gross and Hagy, 2017) and integrate multiple scales of decision makers (Greening and Elfring, 2002). Building such management plans requires effective communication to build publics' awareness about the complexities of aquatic nutrient pollution.

Despite the difficulty (Boesch, 2006) and limited success in building awareness around nutrient pollution (Osmond et al., 2010; Greening et al., 2014; Perry et al., 2020), we argue that the extensive research in communicating climate change can provide insight into effective communication strategies that can motivate public action. Climate change and nutrient pollution have historically progressed slowly, resulting in "shifting baselines" (Pauly 1995) of system status. Originally used to refer to changing fish biomass (Pauly, 1995), shifting baselines for nutrients (Duarte et al., 2009) and climate (Moore et al., 2019) reflect that systems have changed such that the reference baseline level today is different than it was in the past. Additionally, climate change and nutrient drivers are similar in having both major point and nonpoint sources, while impacts are similar in being both localized and widespread. While impacts of nutrient pollution are generally localized, the larger scale of the Haber-Bosch process for industrial production of reactive nitrogen for agricultural use has lowered costs, enabling broader application and thereby expanded the spatial scale of nutrient pollution (Fowler et al., 2013). Higher availability and more widespread use of reactive nitrogen leads predictably to increased losses to surface waters. We argue that the similar challenges in communication for climate change and nutrient pollution of the slow impact, shifting baselines, and diversity of sources create an opportunity for nutrient communication to learn from climate change communication and apply best practices.

Along with the many similarities between nutrients and climate change, there are also notable differences. Although both are "slow" the timescale is meaningfully different for the two issues (**Figure 1**). With nutrients, the entire transition from pristine, to polluted, to recovered could potentially occur within a person's lifetime (Pérez-Ruzafa et al., 2019). In contrast, many of climate change's most severe impacts are occurring across generations and the possible time to recovery is unknowable.

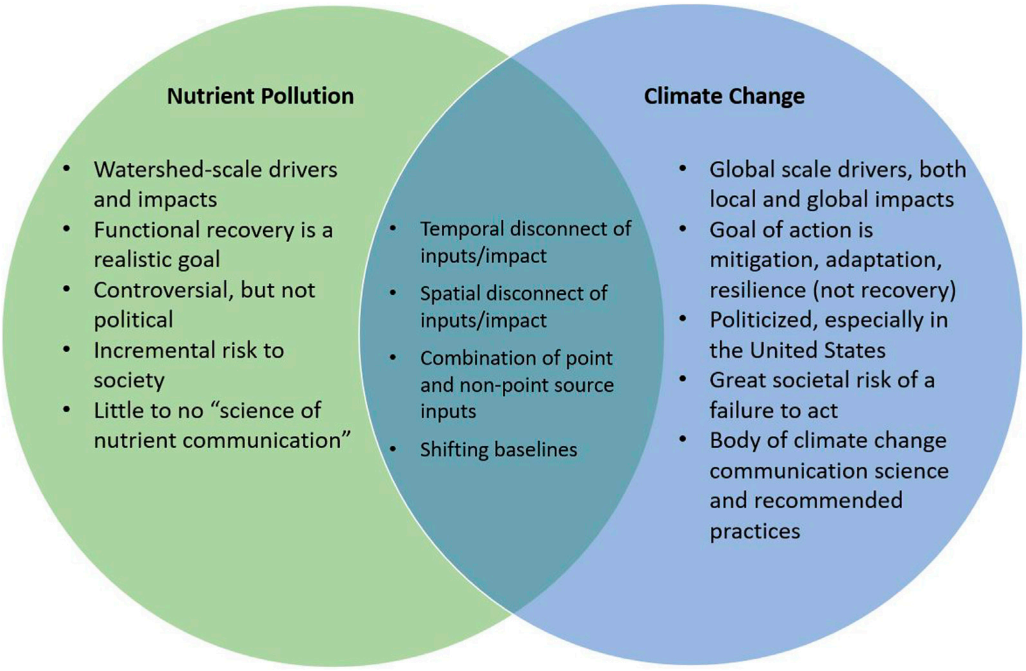


FIGURE 1 | Venn Diagram of similarities and differences between environmental issues of nutrient pollution and climate change.

A further difference is that nutrients generally result in more localized impacts in coastal waterbodies and climate change has less bounded environmental consequences. An additional relevant difference is that there has been extensive interdisciplinary effort to mobilize publics around the globe to act against climate change. We present these examples here to clarify that lessons from climate change are applicable, with tailoring to the nuanced differences of these stressors.

In this paper we respond to the current lack of scientific research on effective science communication on nutrients and management and address the need for researched recommended communication practices. We explain how climate change communication applies lessons of effective science communication within the difficult bounds of motivating action to respond to slow impacts. We then present our analytical approach, which uses qualitatively coding of peer-reviewed and grey literature. In the results section we discuss the findings of our literature review of climate change communication and the ways nutrients science communication may differ from climate change communication in its barriers to effective practice. We then present the best practices drawn from climate change communication that arose as themes from this literature review and integrate applications to nutrient communication in coastal environments. We rely heavily on climate change communication throughout because there is minimal research (Boesch et al., 2001; Boesch, 2006; Osmond et al., 2010; Perry et al., 2020; Reddy et al., 2020) on best practices for nutrient communication. We conclude by reiterating key points about the value of connecting these environmental communication topics that are salient for nutrient scientists and communicators.

Literature Review

The "science of science communication" refers to the study of the state of science communication and public engagement with science (Fischhoff and Scheufele, 2013). Among other areas of research, past science communication work includes how various social identities are or are not actively included in various science learning environments (Dawson, 2014; Massarani and Merzagora, 2014; Streicher et al., 2014; Canfield et al., 2020), efforts at broadening participation in science (Bevan et al., 2018), ways of knowing in science (Eveland and Cooper, 2013; Medin and Bang, 2014), analyzing how various publics process scientific information and apply it to decisions (Dilling and Lemos, 2011; von Winterfeldt, 2013), assessing the structural limitations to scientists producing useful communications (Anderegg, 2010; Scheufele, 2013), and climate change communication (van der Linden et al., 2015; additional sources below).

As an introduction to the critical approach of the science of science communication, we present potential misconceptions in use of the phrase "public understanding of science." An initial nuance of communicating science is that rather than there being a monolithic "public" with a shared understanding of science, there are instead a variety of publics. These publics have differing education, experiences, and beliefs that lead to different understandings of science (Kisiel and Anderson, 2010). As an example, the terminology, objectives, and assumptions associated with the knowledge needed to communicate with an audience of elementary school children are different than for a room full of policymakers (Burks and Menezes, 2018).

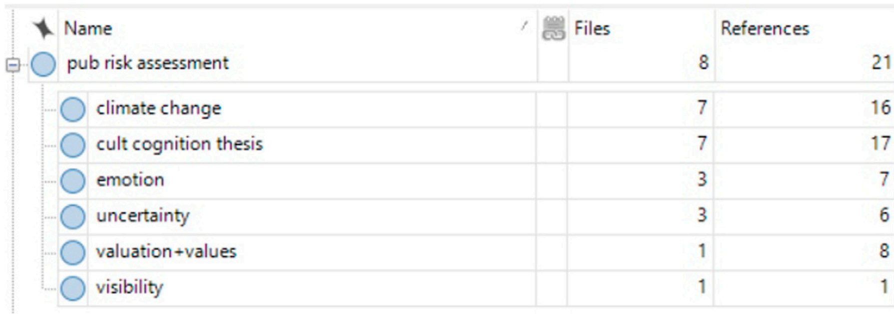
This conceptualization of "public understanding of science" reveals a rhetorical distance between scientists and non-scientists that complicates building a community or societal understanding of science outside of research institutions. The widely debunked "deficit model" (Wynne, 1992; Nerlich et al., 2010) refers to a one-way transfer of knowledge from experts to lay people, which assumes people who are not in traditional scientific research roles have no scientific understanding, just beliefs based on experiences (Wynne, 1992). This model exemplifies a false dichotomy in scientific understanding. Scholars of the science of science communication point out there are both formal and informal ways people know and are exposed to science (Stocklmayer et al., 2010), including formal education (DeBoer, 2000), informal learning (Reich et al., 2010; Dawson, 2019), and traditional and indigenous ways of knowing (Johnson et al., 2014; Lemus et al., 2014). Differing ways of knowing and beliefs (e.g., political affiliation and religion) result in differential trust in scientific research, especially as related to climate change (Brossard and Scheufele, 2013; Eveland and Cooper, 2013; Wang et al., 2018). Notably, distrust in science also arises based on identity, especially social constructions of race, due to historic and continued exploitation (e.g. HeLa cells and the Tuskegee Study) of people with marginalized identities (Suite et al., 2007; Scharff et al., 2010). How information is accessed and assimilated leads to various communities of understanding and acceptance of science that are the product of more, or less, effective science communication efforts in conversation with historic injustices, social norms, and individual values. With the case of climate change, we present some theories of how these communities of understanding develop, and we describe efforts to conduct science communication that positively impact publics' understanding.

One of the largest subfields within the field of the science of science communication is specifically focused on climate change communication. This subfield investigates how people process and apply the science of climate change in their daily lives and how communicators can design communications that motivate communal action on climate change. Several failed attempts to communicate and motivate action around climate change have led to extensive research to understand why this specific area of science communication is so difficult. Two important difficulties are 1) conveying the risks associated with a changing climate to people with different ways of thinking and 2) explaining the urgency of action, which we focus on in our results.

METHODS

In order to identify key themes for communication, we used qualitative coding of peer-reviewed literature. Papers were collated based on the topics of the science of science communication, public engagement with and communication about climate change, and to a lesser degree nutrient science and communication. Papers were identified using Google Scholar, searching keywords and keyword phrases (Mase and Prokopy, 2014). The keyword phrases included "science of science communication," "climate change communication," "public engagement with science," "recommended practices" + "climate change communication," and "psychology of climate change communication." Google Scholar was used rather than a specialized academic database due to the interdisciplinarity of the topics of interest and Google Scholar's ability to support a more inclusive search of relevant scholarly work. Google Scholar has been identified as the most comprehensive academic search engine (Gusenbauer, 2019), and has addressed past concerns over transparency and vetting of articles as the search tool has matured (Halevi et al., 2017; Martín-Martín et al., 2018). When our selected keyword phrases were searched in Web of Science, only climate change communication produced similar results. During review of those papers identified from the initial search, additional relevant papers were identified from the literature cited and were also coded. A keyword search to identify relevant articles on nutrient communication included searching "nutrient communication," eutrophication + communication, nutrients + communication, and "science communication" + "nutrients," with only five relevant articles discussing communicating about nutrients (Boesch et al., 2001; Boesch, 2006; Osmond et al., 2010; Perry et al., 2020; Reddy et al., 2020). Articles that took an applied social science approach that presented the state of understanding of the fields and research-informed recommended approaches to science communication, climate change communication, and nutrient communication were included from these searches. Based on the articles identified from keyword searches, a total of 66 articles were coded (see supplementary materials for citations), with additional articles reviewed but not coded when found to be irrelevant.

Qualitative coding is a method that can be applied in multiple ways (Elliott, 2018). The method allows for sifting through dense data such as text or interviews (Creswell, 2015). It can be applied using a systematic approach (Khan et al., 2003), and can also be used to identify emergent themes inductively (Mase and Prokopy, 2014). We used the NVivo 12 qualitative analysis software to inductively identify codes in the selected papers. Emergent themes were identified based on the analytical focus of recommended practices for effectively communicating science, and specifically communicating climate change, leading to nested codes including best practices for science and climate change communication, and academic limitations to effective communication. One researcher was responsible for all coding to ensure reliable and consistent identification and application of codes across papers. A total of 70 codes were identified using a tiered system wherein the first-level category was more general, and within this first tier was a second tier of the related codes that were more pointed or conceptual aspects within the general category (Creswell, 2013; Elliott, 2018). For example, a first tier (relatively general) category was "public risk assessment" in which general comments on public risk assessment were coded. The second-tier codes within this category specify different analyses and topics that affect how publics assess risk as relevant to science: climate change, cultural cognition thesis, emotion, uncertainty, valuation and values, visibility



Name	Files	References
pub risk assessment	8	21
climate change	7	16
cult cognition thesis	7	17
emotion	3	7
uncertainty	3	6
valuation+values	1	8
visibility	1	1

FIGURE 2 | Screenshot of NVivo 12 showing coded articles related to public risk assessment. Public risk assessment is the first tier category, and those listed below it were the codes identified as existing within the larger category.

(**Figure 2**). Recommended practices for climate change communication and nutrient communication were chosen based on the codes that were consistently identified across the literature as best or recommended practice.

RESULTS

Effective science communication for reducing nutrient pollution is important, but best practices remain greatly understudied, with only five papers found that review nutrient communications. The review of the much broader literature on science and climate change communication therefore provides lessons on the theory and use of science communication for climate change that can then be applied to communicating nutrient pollution. First, we present the findings related to the theory of how people think about climate change and what makes it difficult to convey the urgency to act, followed by explanation of the differences between nutrient and climate change communication. We then describe our thematic findings on the effective practices of climate change communication and their application to nutrients.

How People Think About Climate Change

Explaining the risks of climate change demands appealing to the different ways people assimilate scientific information through their mental models (Bruine de Bruin and Bostrom, 2013). Mental models refer to how people reconcile scientific information with their beliefs (Einsiedel, 1994; Scheufele, 2013). Mental models are constructed from values that are the sum of lived experiences, education, and beliefs that become tacitly accepted knowledge frames for decision making, risk assessment, and evaluation of scientific information (Fischhoff and Scheufele, 2013). These models have been found to be particularly helpful in predicting people's behavior in relation to environmental issues, such as climate change, that allow them to dissociate their implication in the problem (Paolisso, 2011). Many people have mental models that allow for accurate interpretation of scientific information (Fischhoff and Scheufele, 2013). These models may have critical gaps in scientific understanding of environmental issues such as climate change, however, due to communication failures such as lack of appeal to emotion and effort to convey complex science (Fischhoff and Scheufele, 2013).

Mental models incorporate two information processing systems: the emotional and the analytical (Slovic et al., 2004; Marx et al., 2007; Roeser, 2012). The emotional system is based on experiences and responds quickly, whereas the analytical system is more deliberate and based on understanding (Marx et al., 2007; van der Linden, 2015). While both of these systems are always used in decision making, some scientists argue that the role analytical processing plays in assessing climate change risk has been overestimated, ignoring the role that emotions play (Slovic et al., 2004; Marx et al., 2007). The role of emotion in risk assessment is known as the "affect heuristic," or "risk as feeling" (Alhakami and Slovic, 1994; Loewenstein et al., 2001; Leiserowitz, 2006; Roeser, 2012). Slovic et al. (2004) and Marx et al. (2007) argue for increased appeal to risk as feeling, such as personal experience, to address a general underassessment of risk relative to that identified by scientific research. Appealing to emotions provides an alternative to presenting complex climate models and statistics that do not align with people's existing mental models and may therefore not be accepted or understood (Marx et al., 2007; Fischhoff and Scheufele, 2013). This appeal to the effectiveness of emotion for communication emphasizes that science communication, and specifically (climate) risk communication is not just about accurate science, but the way that science is conveyed to different publics (Hertwig et al., 2004; Weber et al., 2004).

In agriculture, mental models have been used to understand the varied values of farmers and how they make decisions (Eckert and Bell, 2005; Prager and Curfs, 2016). This research helps scholars understanding farming choices (Eckert and Bell, 2005; van Hulst et al., 2020), and can be informative for extension educators (Eckert and Bell, 2005) and policymakers (Prager and Curfs, 2016). To date, this work appears to have not focused on nutrient management or pollution, nor specifically on the communication implications, as reflected by the lack of articles on nutrients and mental models in our literature search.

The cultural cognition thesis supposes that belonging to religious, political, or other social groups can explain the different ways people process information (Kahan et al., 2011; Kahan, 2015) and, like mental models, provides an explanation for how social group membership can impact risk assessment. The argument behind cultural cognition is that people are "cognitive misers" and tend to minimize the amount of thinking they have to do that complicates their existing beliefs, and thus rely on their cultural beliefs to simplify processing of new information (DiMaggio, 1997; Eveland and Cooper, 2013). With this desire to minimize processing of excess information, the thesis explains that people more willingly accept information that aligns with their group affinities rather than considering all information presented as having equal potential to be true. In the case of climate change in the United States, Kahan (2015) found that political affiliation predicts acceptance of climate change as scientific fact better than education level. Cultural cognition explains that belonging to a certain religious (Nisbet and Scheufele, 2009; Kahan, 2015) or political groups (Gauchat, 2012) is associated with amount of trust in science, which affects beliefs about climate change. To avoid overstating the power of this thesis to fully explain multidimensional social issues, we note that political ideology is but one characteristic of an individual, and that work on cultural cognition has been focused largely around the case of differing American views on controversial societal issues (van der Linden, 2016). Thus, we acknowledge that this thesis is a useful example of how group membership impacts interpretation of contentious scientific and societal issues within the U.S. context, but should be carefully applied in other circumstances.

Conveying Urgency to Act

One climate concept that demands better communication is the urgency of action around climate change (Leiserowitz, 2005; Lorenzoni and Pidgeon, 2006). Compared to the 2014 assessment, the 2018 National Climate Assessment shows increased action among businesses, communities, and governments to reduce the risks of climate change, although current actions were not found to address the full risks of climate change (USGCRP, 2018). The insufficiency of current actions points to the continued gap between the statistical risk of climate change and interpretation of that risk relative to other factors considered by community leaders and decision-makers. Researchers have identified the perceived "remoteness" (Hoijer, 2010) and abstraction of climate change (Leiserowitz, 2005; Spence et al., 2012; Nurmis, 2016; Wang et al., 2018), along with reliance on analytics and statistics (Marx et al., 2007) in communications as causes of such a disconnect between statistical and perceived risk. Whereas the general population does not perceive imminent risk due to climate change, perception of risk increases when the consequences are visible, immediate, and nearby. This difference has been highlighted in 2020, as publics contrasted how the urgency with which the media presented the crisis of, and potential solutions to, the COVID-19 pandemic and the lower urgency associated with climate change, which has made it much less prominent in the major news cycle (Peters, 2020; Regan, 2020; Roth, 2020). Further confusing the perceived sense of urgency around climate change is misinformation on the scientific consensus behind climate change (Cook, 2019), which encourages a dismissal of the threat.

The distancing of oneself from climate change aligns with the understanding that humans tend to prefer immediate over future benefits (Maibach et al., 2008) and, similarly, deferred expenses over immediate sacrifices (Meyer, 2013). Since the benefits of acting on climate change often are at a scale that is difficult for humans to comprehend, there is a lack of motivation to understand the risk or act with urgency. Another potential explanation for the lack of extensive perceived risk of climate change is deemed the "finite pool of worry" (Linville and Fischer, 1991; Madhavan, 2011). As people become more concerned about one given risk, their concern for other risks decreases (Hansen et al., 2004; Marx et al., 2007). For example, when the concerns of Argentinian farmers increased in relation to climate change, their concern about local politics decreased, even though the political dynamics in the community had not changed (Linville and Fischer, 1991). Taken together, abstraction of climate change, a finite pool of worry, and people's mental models provide a psychological explanation of why climate change risk is rarely acted on, or addressed by, publics at a scale commensurate with the projected impacts.

Social marketing is one approach that has been touted as having great potential to create an urgency to act. Social marketing refers to the systematic use of marketing techniques over the long-term to achieve specific behavioral goals for social good (Lazer and Kelley, 1973). This differs from other kinds of marketing where changing behavior for commercial reasons is the goal (Wiebe, 1952; Maibach et al., 2008). The social marketing approach has become renowned as an effective strategy to go beyond the "pamphlet approach" of providing people information on a subject (Corner and Randall, 2011:1007), and focuses on creating long-term change in specific publics' behaviors for social good (Fox and Kotler, 1980; Peattie and Peattie, 2009). Building an effective campaign relies on researching consumers values and segmenting the audience of the campaign based on these values to create efforts targeted to different values. A review of ocean sustainability social marketing campaigns found that preliminary research on audience knowledge, identities, and values is essential to achieving the desired campaign outcome and understanding campaign leaders' choices (Bates, 2010).

Critiques of social marketing as a strategy for climate change communication and engagement point out that these efforts are largely aimed at changing individuals' behaviors rather than creating community-level, policy, or systemic shifts in practice (Maibach et al., 2008; Corner and Randall, 2011). Additionally, while it has proven advantageous to tailor messaging on behavior change towards the specific intrinsic values of a group (or a specific mental model) (Bolderdijk et al., 2013; van der Linden, 2015), such efforts are not worthwhile if promotion interferes with pursuing the longer-term goal (Corner and Randall, 2011; Corner et al., 2014). In the case of climate change, the larger goal of a societal commitment of addressing fossil fuel emissions requires people to adopt behaviors in line with self-transcendent and pro-environmental values and conservation. However, these goals are incongruent with an audience segment of a social marketing campaign known to have highly materialistic values. Highlighting the monetary benefits of energy efficient light bulbs may appeal to this segment's self-enhancement values. Ignoring the centrality of environmental sustainability in catering this message, however, will lead to a failure to achieve the larger behavioral change towards conservation-minded and sustainable consumption (Deci et al., 1999). Additionally, one principle of social marketing is the "exchange" of the benefit and cost of behavior change (National Social Marketing Centre, 2006; Corner and Randall, 2011). If the exchange requires an incentive to motivate a behavior change that is contrary to a person's beliefs, research has found that as soon as the incentive is removed, individuals revert to past practices (Crompton, 2010; Corner and Randall, 2011; Corner et al., 2014). One of the few articles that mentioned effective communication on nutrients noted that incentives need to be associated with education and regulations to create lasting behavior change (Osmond et al., 2010). A final critique notes that communication approaches that "sell" issues to promote public engagement foster caution and cynicism rather than community support (Walls et al., 2005; Doubleday, 2007; Corner and Randall, 2011). Evidence shows that when it comes to publics with pro-environmental values, social marketing promotes positive behavior changes, suggesting how key these values are in behavior change and scientific communication (Maibach et al., 2008; Corner and Randall, 2011). Thus, using social marketing along with other tools from the climate change communication strategy toolbox can help balance the associated benefits and risks.

Differences Between Climate Change and Nutrient Communication

As demonstrated above, climate change communication has an extensive library of scholarship. Contrarily, five articles were identified as discussing nutrient communication, which presented important lessons learned (Boesch, 2006; Osmond et al., 2010; Boesch, 2019; Perry et al., 2020). Three of these focused on evidence-backed recommendations for communication moving forward (Osmond et al., 2010; Perry et al. 2020; Reddy et al., 2020). Significant space remains for building a more expansive body of literature of evidence-backed practices for nutrient communication. Until then, finding connections to existing bodies of literature can provide valuable support to inform nutrient communication practices.

While there are many similarities in communicating about climate change and nutrient pollution, there are also important differences to be aware of in comparing communication approaches. As already highlighted, the "slowness" of the impacts of climate change and nutrient pollution occur across different timescales. This requires adjusting communications to reflect that climate change impacts are largely intergenerational while nutrient pollution impacts are felt within a generation. Failure to make such adjustment in conveying the impacts of nutrient pollution would inaccurately represent the issue, response rate of the system, and potentially further confuse recipients of such communication. Additional differences we identified were the spatial scale of the environmental challenge, the end goal of publics' engagement, and the politicization of the challenge in the United States. In addressing these differences, we reiterate the call to adjust the approach as the context changes.

The context of addressing climate change is different than nutrient pollution given the scale of climate change is explicitly global while nutrient pollution impacts are often relatively local in scale. Climate change does have localized impacts, such as coastal flooding from rising sea levels, but these impacts are the result of both local climate change preparedness and global scale management of climate due to the connected nature of the system. Compared to climate change, nutrient pollution results from more localized actions and management (i.e., watershed scale). As a result, its consequences are experienced most directly by humans in the watershed, noting that major rivers can also cross political boundaries and impact downstream users separated from sources, and atmospheric nitrogen pollution is usually regional or national. While those communicating climate change and nutrient pollution need to localize the issue to the scale of the system, the spatial disconnect is often not as extreme for nutrients. This makes localizing the cause and effect for relevant publics more straightforward, as the problem is generally most effectively managed at the local watershed scale (Gross and Hagy, 2017). With climate change, communicators are challenged with identifying relevant local impacts or proxies of a global issue that will be meaningful to the various communities that they work to mobilize (Linville and Fischer, 1991; Marx et al., 2007). As communicators are contending with an issue with both point and nonpoint sources, they must overcome the ease with which people can distance themselves from localized contributions, and the challenge of whose responsibility it is to manage the problem.

Nutrient pollution also differs from climate change in the end goal of public engagement. With climate change, the goal is often to mitigate impacts, adapt to new environments, and build resilient societies rather than to return to a historic environment. In nutrient management, the goal is often to recover the functioning of ecosystems, lakes, or estuaries (Duarte et al., 2009; Verdonschot et al., 2013; Gross and Hagy, 2017). This recovery is often to a different state than the system before becoming polluted (Duarte et al., 2009), but still is a restoration of or return to (Duarte et al., 2015) a functioning system (Carstensen et al., 2011; Pérez-Ruzafa et al., 2019). The full removal of nutrients from a system is not always possible (Palumbi et al., 2008), and past work has called for the need to have realistic goals in nutrient management (Weinstein, 2008). However, the possibility of such restoration of ecosystem functions provides a visually compelling message to motivate publics' participation in calls for management. Significant improvements in ecosystem functioning are possible within five years of addressing point source pollution (Taylor, 2006), though full recovery in managing larger nonpoint source nutrients takes longer (Lefcheck et al., 2018). While recovery in nutrient pollution cases, such as when nutrient flows have been reduced quickly with sewage treatment plants (Taylor, 2006; Greening et al., 2014), has been observed, rapid shutoff of greenhouse gas emissions to know what recovery from climate change could look like has not been done.

TABLE 1 | Different terminology used in framing environmental challenges around either the source or the outcome, with a couple of papers as examples of each. Note that these citations often used more than one of the terms in their issue category.

	Nutrients	Climate
Source	Excess nutrients/nitrogen (Smith et al. (1999), Davidson et al. (2012), Van Meter et al. (2016))	Greenhouse gas emissions (Kennedy et al., 2009; Riahi et al., 2011)
Outcome	• Eutrophication (Cloern (2001), Glibert et al. (2013)) • Nutrient pollution (National Research Council (2000), Beck and Hagy (2015), Gross and Hagy, (2017)) • Harmful algal blooms (Glibert and Pitcher, (2001), Sutula et al. (2017)) • Hypoxia/hypoxic zones (Howarth et al. (2011), Van Meter et al. (2016))	• Ocean acidification (Doney et al., 2009; Kroeker et al., 2010) • Global warming (Root et al. (2003), Zhang et al. (2004)) • Climate change (Rosenzweig et al. (2008), Monroe et al. (2019)) • Sea level rise (Church and White (2006), Nicholls and Cazenave (2010))

Another difference impacting public engagement is the different severity of risks posed for these two environmental challenges. Nutrient pollution presents important concerns of impaired water quality and in most cases incremental loss of benefits from coastal ecosystems. In contrast, climate change presents impacts that may be extremely severe and have the potential to profoundly change human society. Climate change requires localizing and concretizing an issue that has potential impacts that are yet to be fully realized, whereas eutrophication from nutrient pollution has numerous examples to which communicators can point (Nixon, 1995; Paerl, 1997). The relatively well-defined impacts of nutrient pollution are at a significantly different scale, and are usually less hazardous, compared to the wide-sweeping impacts anticipated from climate change (IPCC, 2014).

Finally, the politicization of climate change in the United States makes communication more difficult than that on nutrients. This necessitates a highly nuanced practice in communicating climate change to people whose political beliefs have become increasingly associated with disbelief in the phenomenon (Anderegg, 2010; Kahan et al., 2012) or those dismissive of critiques of climate science (Van Rensburg and Head, 2017). Nutrients are not free of politicization. During in the 1960s and 1970s the link between phosphates in detergents and water pollution, especially around the Great Lakes was highly politicized. Environmentalists and residents mobilized to call for government action to address water quality. While they were at first at odds with politicians and businesses that claimed detergent companies could self-manage, eventually phosphates were banned from detergents (Kehoe, 1992). While still not an apolitical issue today, nutrient management does not currently face the same national political polarization as climate change and other issues such as genetically modified foods and stem cell research (Kahan, 2015; Kahan et al., 2015). This could be because while there are whole centers focused on identifying how people think about and communicate climate change in the United States (Maibach et al., 2009), centers explicitly focused on understanding how people think about nutrient pollution and science are lacking. While nutrient pollution communicators and scientists may still currently face issues with distrust in science (Bauer, 2006; Scheufele, 2013), they do not have to overcome mass media disproportionally presenting conflicting views (Eveland and Cooper, 2013; Petersen et al., 2019) of the causes and impacts of excess nutrients.

One notable shared difficulty in communicating nutrient pollution and climate change is the lack of clarity in the messaging distinguishing between the overall processes and individual consequences of these challenges. The changing framing within research areas and between disciplines creates different vocabularies to describe issues with the same, or extremely similar sources (see **Table 1** for some examples). This creates muddled messages for publics not versed in connecting the processes of climate change or excess nutrients with their consequences. For example, in the literature, *climate change* is consistently used to refer to the societal scale, abstract result of increased greenhouse gas pollution, while some speak specifically about *sea level rise* and others create a distinct discourse about *ocean acidification*. With nutrients, the framing is often *nutrient pollution*, but terminology of *excess nutrients*, or the impacts of *harmful algal blooms* and *eutrophication* are also used to refer to the same problem. When choosing terminology, communicators need to present clear messaging of which terms describe the environmental processes, impacts, and their relationships to improve message effectiveness. Additionally, the framing of the terms eutrophication, algal blooms, climate change, and sea level rise is all based on the impacts of nutrients and greenhouse gas pollution rather than on the sources or inputs. This provides another way for people to distance themselves from their responsibility in contributing to these challenges. Addressing these variations in framing consequences of environmental processes within the community of scientists working on issues related to climate change and nutrient pollution could streamline communication and build collaborative networks of scientists (Anila, 2017). Building a more explicitly defined and agreed upon vocabulary of terms within fields would also make the science more accessible to publics outside of these disciplines, as it would demand scientists clearly define the meanings and bounds of the terms they use.

Key Themes of Climate Change Communication Practices for Application to Nutrients Communication

The key findings related to practice of climate change communication fit under the themes of the importance of training and the importance of framing. Training refers to preparing scientists and communicators to share their messages or motivate publics. The theme of framing contains topics and analyses on the content and approach for sharing climate change messages with diverse publics. Together, these themes identify both the past shortcomings in climate change communication and recommended approaches for increasing publics' awareness and action to address climate change.

Training

Scientific researchers may struggle to produce science communication materials that are useful for their intended audience or users due to a lack of training in, or anticipated reward for, production of such materials (Jacobson et al., 2004; Nisbet and Scheufele, 2009). Some scientists may not know who the relevant or target audience of their work is, due to a belief that science is for knowledge production alone (Dilling and Lemos, 2011) or due to a lack of training and subsequent experience in the identification of relevant users of their science and their needs (Fischhoff and Scheufele, 2013; Nerlich et al., 2010; von Winterfeldt, 2013). An inability to identify end users can result in a tendency to focus communications on what researchers find interesting and important (Bruine de Bruin and Bostrom, 2013; Scheufele, 2013). Not tailoring information for use by publics other than scientists can result in available science being largely comprehensible and accessible for other researchers in a similar research area (Marx et al., 2007; Dilling and Lemos, 2011; Bruine de Bruin and Bostrom, 2013; Scheufele, 2013). Others may want to use science to influence policy, but lack understanding of how to do so (Hetherington and Phillips, 2020). While it is too simplistic to claim that scientists are totally responsible for all scientific communication, the science of science communication emphasizes the need to break down the strict boundaries of categorizing people as scientists or nonscientists in order to produce more useful science communication products.

Lack of training in science communication (Anderegg, 2010; Dilling and Lemos, 2011; Fischhoff and Scheufele, 2013; Scheufele, 2013) highlights whether academic research systems are designed to prioritize effective science communication by researchers (Jacobson et al., 2004), or if that is even a researcher's role. In the case of universities with extension offices, researchers argue these offices are to serve as information brokers that translate and communicate science to relevant stakeholders (Prokopy et al., 2015). Alternatively, researchers might work with nongovernmental organizations or news media to produce science communication products (Boesch, 2019). However, this still assumes that scientists have the intrinsic motivation, time, and/or skills to work closely with people outside of academia to produce materials for publics outside of their area of expertise. This is not a critique of scientists' values, but rather a questioning of whether research systems as designed have provided the support for researchers to do science communication beyond academic conferences and papers. The lack of academic rewards for engaging with publics on science (Anderegg, 2010; Dilling and Lemos, 2011; Singh et al., 2014) might explain why researchers may not claim ownership of the task of communicating their science (Dilling and Lemos, 2011). The literature reveals that within the theme of training, there are subthemes, including lack of preparation of scientists in communication, the understanding that scientists are not necessarily science communicators, and a lack of professional recognition for communication work.

Framing

Framing arose as a theme based on the consistent emphasis across the literature on building messages that are designed for the various ways people assimilate and apply scientific knowledge (Scheufele, 2013). The five topics that emerged as essential for framing are:

1. concrete vs. abstract examples (Marx et al., 2007; van der Linden et al., 2015).
2. mental models (Nerlich et al., 2010; Dilling and Lemos, 2011; Bruine de Bruin and Bostrom, 2013).
3. imagery (Corner et al. 2014; Nerlich and Jaspal, 2014; Metag et al., 2016; Eskjær, 2017; Wang et al., 2018).
4. positive vs. negative messaging (Nerlich et al., 2010; Gifford and Comeau, 2011), and
5. social norms (Corner and Randall, 2011; Gifford and Comeau, 2011; van der Linden et al., 2015; Wang et al., 2018).

Both designing messages with a focus on the concrete rather than abstract and being aware of peoples' mental models were discussed across the other three topics. Concrete examples based on real weather events (Marx et al., 2007; Bloodhart et al., 2015) and localized experiences (Nicholson-Cole, 2005; Wang et al., 2018; Monroe et al., 2019) have been found to mobilize communities more than relying on abstract ideas or projected models of extreme weather or esoteric statistics (Marx et al., 2007).

Regarding imagery, the literature noted that there is a persistent abstraction in much climate change imagery (Wang et al., 2018). The image of the polar bear, which has become associated with climate change (Doyle, 2007; Leviston et al., 2014; Swim and Bloodhart, 2014), is an abstraction because most humans never interact with a wild polar bear. Other examples of abstractions include use of politicians (Rebich-Hespanha et al., 2014), public figures and protestors (Smith and Joffe, 2009; O'Neill and Smith, 2013), and scientists (Leon and Erviti, 2013). Non-abstract images of climate change could include narratives that outline the impacts of climate change on "ordinary" humans or other stories including humans (Corner et al., 2015) and emotion (Marx et al., 2007; Meldrum et al., 2012) in visualizations. Such visualizations have been found to reduce the psychological distance perceived with climate change (Swim and Bloodhart, 2014; Wang et al., 2018). Specifically, appealing to positive emotions rather than fear has been an important topic in framing climate change messages and imagery (Leviston et al., 2014). Apocalyptic visualizations of climate futures may aim to stand out against the imagery of daily life (O'Neill and Nicholson-Cole, 2009) but instead serve to further distance people from the desired engagement (O'Neill and Nicholson-Cole, 2009; O'Neill and Smith, 2013). As was previously noted, people have a finite capacity for worry at any given time (Linville and Fischer, 1991; Madhavan, 2011). Evidence suggests that to mobilize people around climate change, appealing to motivation is more effective than stoking fear and calling for sacrifice (Nerlich et al., 2010; Gifford and Comeau, 2011).

Activating social norms is another topic relevant to framing and mental models. Activating social norms involves framing climate change as a "social reality" that affects people's ways of living (Rowson, 2013; Corner and Clarke, 2016; Pearson et al., 2016; Wang et al., 2018). As people are social beings, if family and friends begin to talk about climate change and mobilize to address climate change, individuals will increase their perception of risk and actions to minimize the risk (Renn, 2010; van der Linden, 2014). Rather than trying to frame messages to shift behavior at an individual scale, appealing to social norms activates and leverages community behavior to create larger-scale mobilization to address climate change (Corner and Randall, 2011; Gifford and Comeau, 2011; van der Linden et al., 2015; Wang et al., 2018).

While adjusting climate change frames did not predict behavior regarding a specific farming intervention (Singh et al., 2020), intentional climate change framing effectively increased support for climate policy (Walker et al., 2018). Acknowledging the role of climate change in natural disasters can have negative effects on the processing of scientific facts for climate change skeptics (Dixon et al., 2019), pointing to the importance of considering the mental models the audience in preparing climate change communications. Though these examples do not argue in favor of one specific method of framing, together, these studies exemplify that the actors and audiences to which information is communicated foundationally affect the effectiveness of a message (Reddy et al., 2020). The recommended practices based on these themes that follow emphasize the importance of context in communication.

Recommended Practices

Our literature review and qualitative coding analysis identified five recommended practices for climate change communication that would also apply to nutrient pollution communication:

1. prioritize two-way communication between publics and communicators,
2. relate to human experience rather than abstract analysis,
3. emphasize local impacts and immediate actions to be taken,
4. define and activate social norms around the problem and urgency of action, and
5. build interdisciplinary collaborations to address science communication training and reward gaps.

Addressing climate change and nutrient pollution with similar communication strategies relies on the similar ease with which publics psychologically distance themselves from their role as causal agents and associated slow and spatially distant impacts. While the principles are transferable, the differences noted above in these challenges necessitate tailoring the principles to the specifics of each stressor and/or situation. Despite the differences between nutrient pollution and climate change, there are similarities in the difficulties of past communication efforts that allow us to learn from scholars of climate change communication. While both the temporal and the spatial disconnect may not be as great for nutrients as with climate change, the shared slow impacts make lessons from climate change communications useful in building motivated publics across sectors to tackle this environmental problem. The five recommended practices for climate change provide an evidence-based starting point to improve communications on nutrient pollution, which we demonstrate with example applications of each of these practices. These examples focus on building publics' understanding of how nutrients enter and pollute water bodies and actions that communities and individuals can take to reduce nutrient loading.

In all science communication, materials that allow give and take among the audience and those preparing such materials ensures that the right questions are answered (Moser, 2010; Dilling and Lemos, 2011; Corner et al., 2014) and that local knowledge and context is addressed (Collins and Evans, 2007; Nerlich et al., 2010). This first practice for climate change communication aims to ensure the science that is shared is relevant and useful to the intended audience (Bruine de Bruin and Bostrom, 2013; Fischhoff and Scheufele, 2013). The need to prioritize two-way communication builds on the shortcomings and failed efforts documented in the climate change communication literature. Recommended practices 2 through 4 further emphasize the need to include local implications of climate change in communications. These three practices reduce the psychological distance of the response (Swim and Bloodhart, 2014; van der Linden et al., 2015; Wang et al., 2018).

In practice, two-way communication on nutrients can include holding public hearings and other forms of consistent meetings on policy and planned management strategies that allow for public comment, that is then meaningfully incorporated into planning documents. Implementing two-way communication requires recognizing the varied priorities and ways of assimilating scientific information that exist across residents, policymakers, scientists, environmental activists, and other groups of people to ensure communications respond to groups' values and needs. Further, consistent interaction with people across the various publics via meetings (in-person or virtual) will ensure that management strategies address the needs of local residents and incorporate the historical knowledge residents have of their communities. To be most inclusive, this communication will need to recognize the expertise that comes from lived experiences as well as that from formal education or official status (Ottinger, 2013). Recognizing lived expertise minimizes the risk of a deficit approach of "talking at" (Lewenstein, 2003; Smallman, 2016) or "selling" (Corner and Randall, 2011) nutrient science to publics, so that communicators instead engage in a constructive dialogue (Nisbet and Scheufele, 2009; Smallman, 2016; Monroe et al., 2019).

Explaining the science in relation to ecosystem services and activities that people are familiar with is helpful to reduce the psychological detachment of nutrient management. This is applicable both to recommended practices 2 and 3. Addressing the local slow impacts and spatial disconnect between inputs of nutrients and their impacts requires finding frames for communications that will motivate engagement. Framing the issue considering something important to local identity, such as beach access in coastal towns or the importance of productive farming in agricultural areas, is one transferable tool to concretize the challenge (Mexico Hypoxia Assessment, 2017). Local residents that define themselves based on where they live will most readily accept an appeal to the value of the environment and natural resources to motivate action (Madhavan, 2011).

One example of making nutrient management less abstract is preparation of an infographic that describes the impacts of nutrient pollution on beach and water quality and beach access and closures. In conjunction with an infographic explaining the science and impacts, localizing the actions that can be taken at the individual, town, county, and state scale to mitigate impacts is also important (Greening and Elfring, 2002). Social marketing could be a useful tool in framing the need to build support for these communal actions that protect natural resources for the good of the local economy and environment among those who already display passion for conservation. However, the power of social marketing and message framing to change conservation behaviors should not be overstated. A recent study on nutrient communication strategies found that in the case of farmers not already engaging in conservation behaviors, message framing towards economic and environmental values was less effective at encouraging conservation than just presenting information on the practice (Reddy et al., 2020). Based on the past work on climate change communicators (Marx et al., 2007) and effective nutrient management (Gross and Hagy, 2017), localizing the problem and benefits is essential to community participation.

To create urgency to change behaviors in a lasting way to address nutrient pollution in coastal waters, the relevant social groups that need to be engaged are likely at both the neighborhood and watershed scale. This is in accordance with the literature arguing for mobilizing publics via social norms rather than targeting individuals. These publics include both people who live in these communities and contribute to the nonpoint nutrient loading and those decision makers responsible for the waterbody. Research has found that targeting normative beliefs, that is, what people believe about the behavior of others, is effective for creating behavior change (Maibach et al., 2008; Paolisso, 2011). This suggests that appealing to a community sense of pride in a less impacted environment, regarding nutrients at least, can be effective for mobilizing resident publics. One application of this could consist of informing residents of the severity of water quality impairments to a watershed, and then building campaigns focused on mobilizing the community at different scales to protect the watershed. It is essential to build and appeal to a shared sense of community up to the watershed scale to ensure communal mobilization to address shared problems at a scale that will have a meaningful impact for the impacted waterbody (Boesch, 2006; Merrill et al., 2018). As people within these communities will likely have slightly different mental models, mobilizing around a shared identity will build a sense of connection and responsibility to protect their community. As a past nutrient communication effort found, increasing understanding of the issue alone has not proven effective in overall nutrient reduction; policy and clear actions at multiple scales are needed to encourage actions with urgency (Boesch et al., 2001; Greening and Elfring, 2002; Boesch, 2006; Osmond et al., 2010).

This brings attention to the important point that while behavior change is an important component of nutrient management, it is the responsibility of coordinated efforts across local, regional, and national government agencies to institute plans and policies for nutrient management (Greening and Elfring, 2002). Past work has emphasized the connection between communication and management. One study found that the most common community motivator to call for nutrient management was when publics became aware of an ecological crisis, media attention further increased awareness, and then publics mobilized to demand government action (Gross and Hagy, 2017). For this call to be successful, Gross and Hagy (2017) found that there needed to be a specific ecological goal, such as restoring seagrass habitats (Greening et al., 2014), reconfirming the need for public mobilization around a concrete issue and action. A recent study further emphasized that to address eutrophication effectively requires sustained engagement of various levels of government in concert with publics, as aware constituents can hold officials accountable to meet identified goals (Boesch, 2019).

The final recommended practice for climate change communication that can translate to nutrient communication is the result of the theme of training and the disconnect between research scientists and the public. Changes in training could build partnerships across interested and relevant organizations such that all necessary skillsets are represented. This aims to overcome the reality that no one organization or individual can have training and expertise across all the disciplines or topics, and thus should not be expected to lead in areas in which they have limited or no training. Relevant experts to connect climate scientists with include social scientists, communication scholars (Anderegg, 2010), extension officers (Prokopy et al., 2015), and science communication practitioners (Fischhoff and Scheufele, 2013) or "information brokers" (Dilling and Lemos, 2011). The objective of science communication is to ensure science is accessible and useful for publics. For this to be the case, science communicators have a mediating role of providing clear translation of scientific information to publics, and to ensure scientists understand what scientific questions are of interest to publics. One of the few articles located that discussed communication on nutrient pollution also emphasized the importance of "boundary organizations" that specialize in science communication and can provide necessary support in translating policy and scientific research into useful information that is relevant to community concerns (Boesch, 2006).

The bookend practices of 1 and 5 together emphasize the need to work with individuals across disciplines or official capacities. This is an asset-based approach (Burks and Menezes, 2018) that aims to incorporate into communications the expertise, or assets, of individuals across diverse backgrounds (Banks et al., 2007; Jensen and Holliman, 2015). Taken together, these five practices are evidence-backed ways to improve sharing of information about climate change, nutrient communication, and increasing public engagement. They are practices that science communicators can use to produce useful communications that support and increase publics' awareness about nutrients and the consequences of pollution, and publics' understanding of management needs. While management plans require looking at a larger scale of the watershed, communications require relating to specific audiences within that watershed, and humanizing complex science for these audiences. In sum, communications serve to support and advocate for nutrient management via communities' increased ability to discuss and identify the problem and potential impacts.

DISCUSSION

The lessons gleaned from the science of climate change communication provide a backbone to improve efforts to communicate about nutrient pollution. A survey at the end of a two-year communication campaign about watershed-scale management of water pollution on Cape Cod, Massachusetts, revealed minimal improvement in communities' awareness of both the local water quality problem and possible solutions (Perry et al., 2020). This has the potential to be a major problem for this tourism-dependent community, as impaired water quality is associated with reduced recreational value (Merrill et al., 2018). In the Neuse River Basin, North Carolina, agricultural runoff is responsible for over half of the nitrogen loading to the estuary and resulted in algal blooms and fish kills for decades. To address this problem, cooperative extension specialists led a nutrient management training program for farmers that increased awareness of nutrient pollution, which both emphasized having a dialogue and preparing education materials (Monroe et al., 2019). At the conclusion of the training, however, a field survey showed the training did not change farmer practices or nutrient loading to the estuary (Osmond et al., 2010). This exemplifies the need for an approach that goes beyond simply sharing information. The challenges faced in changing behavior in both these efforts show that a strategic communication approach (Besley et al., 2019) is essential, and that communications are not a standalone solution to a systemic problem. Continuing efforts to build publics' and policymakers' understanding and buy-in to nutrient management is essential (Druschke, 2013). This must be done in conjunction with management strategies that further encourage and enforce behavior change. Finally, while these efforts leave space for improvement, they also demonstrate a focus on localized impacts and examples that climate change communication could benefit from adopting in concretizing messages.

Throughout this paper, we have strived to show the transferability of communication practices between climate change and nutrient pollution. This has been primarily based on the slow impacts and spatially detached drivers and impacts, but the transferability is also due to the interconnected and widespread nature of these issues. As the climate changes, eutrophication that already impacts most U.S. estuaries (Howarth et al., 2000) is expected to worsen in global waterways (Howarth et al., 2000; Alam and Dutta, 2013). Additionally, improved nutrient management is an important part of mitigating climate change due to gaseous nutrient pollution. When comparing the ability of greenhouse gases to warm the atmosphere, nutrient pollution in air as nitrous oxide is 300x as potent as carbon dioxide (Forster et al., 2007; EPA, 2020a). As these issues are intertwined, communications that encourage behavior and policy that improves environmental quality for one of these issues indirectly benefits the other (Russell et al., 2009). The recommended communications strategies are most definitely applicable in building awareness and presenting behaviors for improved environmental quality for both environmental challenges.

Based on the literature review and qualitative coding of the research, five recommended practices for climate change communication were identified that are easily transferred to nutrient communication. The communication practices we identified share an underlying emphasis on relating communication to the societal and environmental context and recognition of the assets that all relevant publics and individuals have to address the environmental challenge. These practices address the need to communicate intentionally between scientists and communities impacted by nutrient pollution such that communications effectively convey urgency across different audiences. They can be applied in navigating communicating slow impacts in a diversity of settings, including across government agencies. Rather than providing a template, the lessons here are of the transferable communications framing, and the need for a multipronged approach to achieve improvements in environmental quality (Osmond et al., 2010). The recommended approach to nutrient communication demands that communicators localize, don't catastrophize; continue to learn from existing efforts; and provide action items specific to different publics' expertise, social groups, and policy power.

As nutrient pollution continues to impact marine waters in the United States and globally and impacts worsen, the need for effective nutrient communication is increasing. The findings from the field of climate change communication provide an important set of evidence-backed practices that can be applied toward improving nutrient communication to mitigate impacts.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

KC, KM, and NM all contributed to ideation, research, writing, and revision.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2021.619606/full#supplementary-material.

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frontiers in Marine Science

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Marine Citizen Science: Current State in Europe and New Technological Developments

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Marine citizen science is emerging with promising opportunities for science, policy and public but there is still no comprehensive overview of the current state in Europe. Based on 127 projects identified for the North Sea area we estimate there might be as much as 500 marine and coastal citizen science projects running in Europe, i.e., one marine citizen science project per ∼85 km of coastline, with an exponential growth since 1990. Beach-based projects are more accessible and hence most popular (60% of the projects), and the mean duration of the projects is 18–20 years. Current trends, topics, organizers, aims, and types of programme in terms of participation are presented in this overview. Progress in marine citizen science is specially enabled and promoted through technological developments. Recent technological advances and best practise examples are provided here, untapping the potential of smart mobile apps, do-it-yourself (DIY) technologies, drones, and artificial intelligence (AI) web services.

Keywords: marine citizen science, inventory, European seas, smartphones, DIY, drones, AI, big data

INTRODUCTION

Why Citizen Science?

Citizen Science promotes the collaboration between non-professionals and scientists and in a two-way process. Citizens can engage in various degrees from co-design and co-creation, through problem definition, data collection, analysis, and dissemination of results, to participation as interpreters of information and sensors (Shirk et al., 2012; Haklay, 2013; Chapman and Hodges, 2017). The benefits are shared: scientists enhance their monitoring and analytical capacities and citizens gain scientific knowledge, awareness, and recognition. The results can further influence local policies (Chapman and Hodges, 2017; Hecker et al., 2019) and the public's involvement can stimulate education initiatives (Sullivan et al., 2014; Dunkley, 2017). Citizen science is in this way increasingly viewed as a way to empower communities by involving them in research that can be used to drive forward policy changes (Rowland, 2012; Sullivan et al., 2017).

The term citizen science was simultaneously coined by Alan Irwin in the United Kingdom and Rick Bonney in the United States in the mid-1990s. However, people have for centuries collected observations in fields such as archaeology, astronomy, and have recorded changes in the surrounding nature (Silvertown, 2009). Outbreaks of locusts were recorded for at least 3,500 years in China, cherry blossoms for 1,200 years in Japan, grape harvest days for more than 640 years in France (see Miller-Rushing et al., 2012 and references herein). Throughout the tropics, forest people, as well as fishers, have accumulated knowledge of their activities-concerning local natural environment that is useful for management purposes (Dalzell, 1998; Michon et al., 2007). Long-term records were kept by both amateur and commercial fishermen and amateur flora and fauna collections enriched most of the natural history museums (see Miller-Rushing et al., 2012).

Data from historical observations and collections are used to analyse shifts in the diversity, abundance, distribution, or phenology of species due to changes in land-use or climate. In recent years, citizen science attracted attention because it allows working on projects otherwise unfeasible. In fields like ecology, chemistry, or astronomy non-professionals strongly contribute to scientific knowledge. For example, exoplanets and comets were discovered by amateur astronomers, galaxies were classified (Lintott et al., 2008; Raddick et al., 2010), new solutions in protein design proposed (Koepnick et al., 2019), new RNA structures built (Lee et al., 2014), and bird populations were monitored (Bonney et al., 2009) by citizen scientists. Invasive or toxic species as well as air, land or marine pollution and many more subjects are monitored or analysed in the framework of citizen science projects and increasingly used in habitats' restoring initiatives (Huddart et al., 2016; Tiralongo et al., 2019, 2020)[1] .

Recent improvements in citizen science are also around institutional organisation. Several citizen science associations have further their collaboration through establishing the Citizen Science Global Partnership (CSGP). Launched in 2017, the CSGP brings together the existing networks of citizen science researchers and practitioners with advisory boards representing policy, business, and community-based perspectives. This initiative was founded in partnership with the United Nations Environment Programme (UNEP) and is also supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO). Among their tasks are to explore the possibilities and difficulties of citizen science to make real contributions toward the UN's Sustainable Development Goals and to work with UNESCO on a global Recommendation on Open Science in 2021. Among their members are regional citizen science associations in the United States (CSA), Australia (ACSA), Ibero-America (RICAP), Asia (CitizenScience.Asia), and Europe (ECSA).

The European Citizen Science Association (ECSA) offers since 2013 a platform for organisations and individuals to interact with other European or worldwide projects, to collaborate in the shaping and development of the different aspects of citizen science, its better understanding and use for the benefit of decision making. Through its working groups, ECSA members have developed the 10 principles for citizen science, and contributed to the citizen science ontology demarcation (Eitzel et al., 2017), developed multiple policy briefs addressing the contribution of citizen science to open science, do-it-yourself (DIY) science, defined principles and collected best practices for mobile applications for environmental and biodiversity citizen science (Luna et al., 2018; Sturm et al., 2018) and systematised the characteristics of citizen science to help users, participants, scientist, policy makers and research funders making open and transparent decisions by following a group of defined criteria for identifying the type of activities that belong to citizen science. It is more and more common that research and educational institutions as well as natural areas managers use citizen science to support their studies and monitoring programmes (Freiwald et al., 2018; Irwin, 2018; Wyler and Haklay, 2018; Zipf et al., 2020).

Environmental awareness-raising of citizens through involvement in scientific activities and education enables decision-making and plays an essential role in increasing adaptation to climate change and its mitigation (Vohland et al., 2021).

Why Marine Citizen Science?

Global change and the consequent impacts to marine systems, the evolving international marine governance and management and the need for greater advocacy and stewardship are drivers and opportunities to strengthen the role of marine citizen science in policy frameworks (Garcia-Soto et al., 2017; European Commission, 2018).

The marine realm is the largest component of the Earth's system, stabilises climate and supports life on Earth and human well-being. Understanding of the ocean's responses to pressures and defining management actions is fundamental for sustainable development. However, citizen science projects in marine contexts encounter challenges not faced in terrestrial systems. These include safety, culture, logistics, accessibility, equipment, etc. This explains the relatively weak presence of citizen science in marine when compared to terrestrial environment. Yet, because of the vastness of the marine domain, the collaboration between large numbers of non-scientists and scientists is particularly urgent and important. Building on precise protocols (Benedetti-Cecchi et al., 2018) and on instrumental developments, the citizen involvement in coastal zone (Vye et al., 2020) and open sea projects is growing. Given the scale of marine environmental threats and the relatively limited resources to fill the knowledge gaps, citizen science approaches in conjunction with new technologies should increasingly be considered to complement the scientific efforts in the marine regions.

In this article we present a first analysis of the current state of marine citizen science in Europe. We analyse trends, topics, organisers, aims, and types of programme in terms of participation using the limited information available. As a second objective the article reviews the role of technology in citizen science and marine citizen science by providing some recent

[1] https://easin.jrc.ec.europa.eu/easin/CitizenScience/Projects

best practice examples of smart mobile apps, DIY technologies, drones and artificial intelligence (AI) web services. The work represents a continuation of our previous joint publication "Advancing Citizen Science for Coastal and Ocean Research" (Garcia-Soto et al., 2017) that analysed additionally Citizen Science data quality control and modelling, Social engagement, impact and education, Citizen Science and marine policy, and the European coordination of project management networks. We refer the reader to that extensive review (115 pp) for information on those topics.

THE CURRENT STATE OF MARINE CITIZEN SCIENCE IN EUROPE

Estimating Size and Trends of Marine Citizen Science in Europe

There are no dedicated databases on marine citizen science initiatives at present. For this analysis, we could rely on a recent quantitative assessment of North Sea projects, coordinated by one of us and reported in van Hee et al. (2020). A project was earmarked as a marine citizen science initiative according to the principles listed by European Citizen Science Association [ECSA] (2015). To be considered a citizen science project the project should involve citizen scientists at least in one of the stages of the research process (sampling, analysis, etc.), and the project should have a real scientific result. The projects were not considered citizen science projects if the citizens were involved only for education purposes.

The comprehensive study of the North Sea, excluding the English Channel, relied on thoroughly checking literature, searching social media and other online sources, and on direct contact with marine institutes and other organisations in the area. For each project, we defined at least the coordinating organisation, the country and area of activity, the language, the duration, the study topic, the type of programme and the level of participation. We estimate, based on that North Sea study and assuming other marine regions in Europe have equal numbers of marine citizen science initiatives, that there might be as much as 500 marine and coastal citizen science projects running in Europe.

In the North Sea area, we could identify 127 projects, of which 94 were either country specific – i.e., taking place in the exclusive economic zones (EEZs) of one of the riparian countries (85) – or targeting the entire North Sea (9). As the North sea counts about 25,000 km of coastline or 19% of Europe's total length excluding Greenland and Iceland (131,322 km)[2], the overall estimate of 500 European projects – both ongoing or suspended – seems realistic and amounts to one project on average for every 250 km of coastline. Provided we exclude the vast coastline of Norway (with "only" 18 ongoing marine citizen science projects) from this calculation, we can derive one marine citizen science project per 84 km of coastline. In comparison, during the summer of 2019 the French Collectif Vigie Mer's census could identify 81 marine citizen science initiatives in French marine waters, i.e., one initiative per 60 km of coastline (Collectif Vigie Mer, 2019).

Whether other marine regions in Europe have a similar density of marine citizen science initiatives, is unknown as no precise figures or reviews are available. However, it is clear from the Mediterranean basin for instance, that marine citizen science is omnipresent there as well with several projects monitoring coral reefs, gelatinous plankton, fish and non-indigenous species (e.g., "Pure Ocean," CIGESMED, COMBER, Med-Jellyrisk, Aliens in the Sea, AlienFish project, Plastic Buster, SeaCleaner, ACT4LITTER . . .; Zenetos et al., 2013; Panteri and Arvantidis, 2015; Merlino, 2016; Kleitou et al., 2019; Tiralongo et al., 2019).

The mean duration of projects in the North Sea is 18–20 years. Some very attractive topics, including birds (37 years) and marine mammals (28 years), have longer lifespans. In Norway, lobster catch data has been voluntarily collected by citizens for 92 years. On the other hand, extreme citizen science projects score much lower, due to their recent character and the higher demands, both from the organiser and the participants point of view (e.g., mean duration of 10 years).

Citizen science is not new, and today there are thousands of examples of citizen science projects in Europe (European Commission, 2018). In the North Sea the oldest project dates back to 1876, a crowdsourcing initiative by the Conchological Society of Great Britain and Ireland (Light, 2016). The project is still running and has been going on for 143 years. After a slow growth, citizen science projects area started turning into an exponential growth from 1990 onward (**Figure 1**) and became more visible from the late 2000s onward probably due to the increased availability of smart mobile phones, and also as the term citizen science gained popularity and more and more people began to use the term or rebranded themselves as citizen science. Nothing seems to indicate that this process is slowing down. On top of that, there is no reason to believe that it would be different for other European maritime regions.

Science Europe (2018) estimates that 25% of all projects (terrestrial, freshwater, and marine) are marine or coastal. Taking into account the vast area ocean and seas (71%) are covering, one could argue that marine citizen science is under-represented. However, when considering the limited access to offshore waters for most citizens and the narrow contact zone where most ocean-oriented projects take place, that should not surprise us. In the North Sea area, beach-based projects, much more accessible for citizen scientists than projects that require data collected at sea, are more common (60% of the projects).

What Topics Are Those Projects Dealing With?

A survey on EU-wide citizen science conducted in 2016 with participants located in the United Kingdom and Germany, reveal the vast majority of projects is active in the field of life sciences (Science Europe, 2018). The North Sea study (van Hee et al., 2020) confirms this statement, a reality that probably applies for marine citizen science in Europe as a whole. Almost half of all projects in the North Sea (48%) study "species" (see categories in **Figure 2A**). Another 16% has a more general "biodiversity"

[2] World Factbook: https://en.wikipedia.org/wiki/List_of_countries_by_length_of_coastline

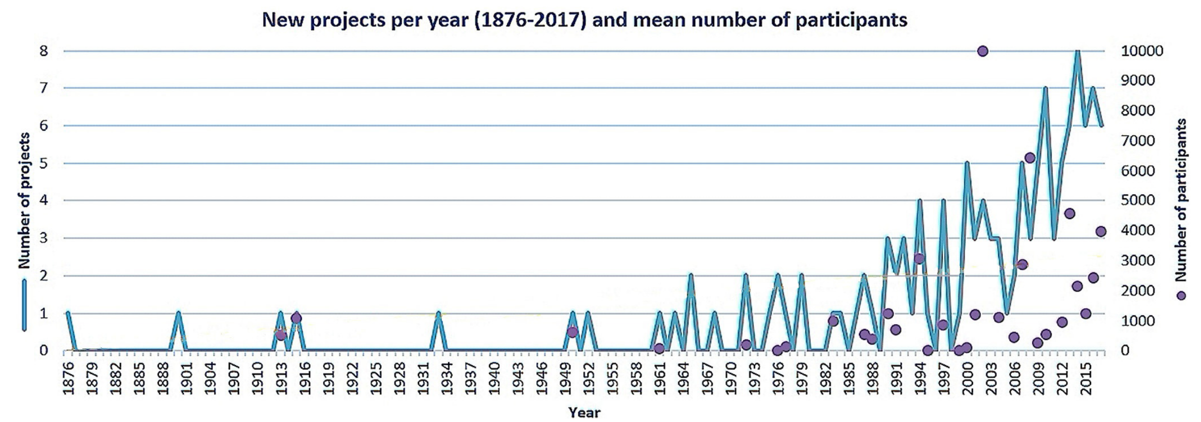

FIGURE 1 | Number of newly started marine citizen science projects in the North Sea and mean number of participants per project (from van Hee et al., 2020).

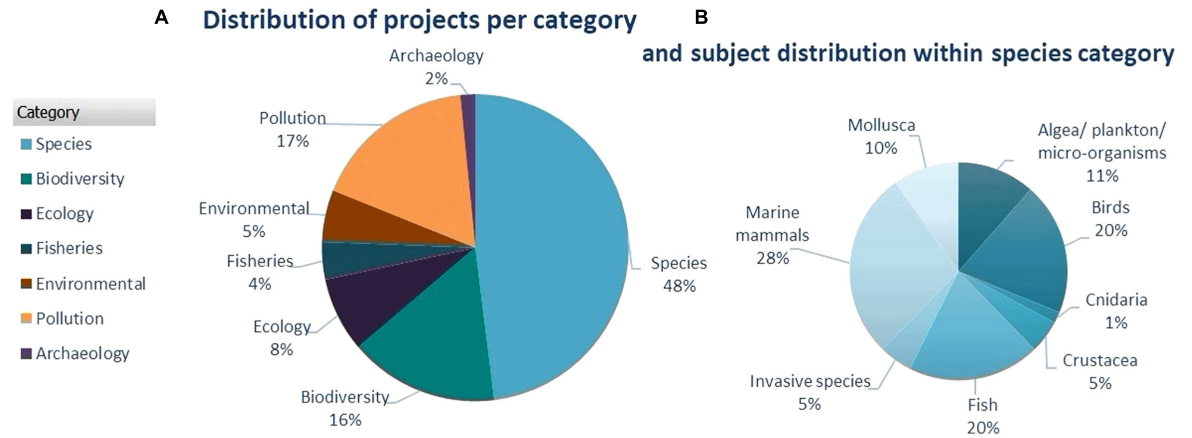

FIGURE 2 | (A) Distribution of marine citizen science projects by topic categories in the North Sea and **(B)** Subject distribution within the "species" category (from van Hee et al., 2020).

focus, collecting information on many different species, for instance to map the biodiversity of a specific region. And the category "ecology" (8%) includes projects on for instance coastal ecology, the state of certain habitats, species interaction with the habitat, or the impact of climate change on the ecosystem. Only 17% of the projects deal with pollution, such as marine litter or the effect of oil spills on birds. The remaining 11% performs research on "fisheries" (fishery catches or fish stocks), "environmental variables" (such as water quality, temperature or sea level rise), and "archaeology" or maritime history. In other parts of Europe the situation is not all that different. In Norway for instance, 78% of the marine citizen science initiatives deal with life science, and in France, life sciences account for 94% of the projects.

Within the category "species research" (**Figure 2B**), marine mammals (28%), fish (20%), and birds (20%) are most wanted, followed by seaweeds and plankton (each 11%) and molluscs (10%) (van Hee et al., 2020). Only seven projects deal with crustaceans, invasive species or cnidarians such as jellyfish. In Norwegian waters, there is relatively more CS activity on crustaceans (19%) and jellyfish (14%), and less focus on seabirds (11%) and marine mammals (17%). In France, many marine citizen science projects are not species-specific but deal with marine biodiversity as a whole (57%), although here as well larger animals (21%) still are well-presented: marine mammals (7%), seabirds (10%), and turtles (4%).

Who Is Organising the Projects? What Are the Aims?

North Sea Citizen Science projects are enabled by a wide-ranging group of stakeholders (charities and foundations, governmental organisations, research institutes, partnerships, individual people). NGOs are the main contributors to North Sea CS-initiatives (56%; see **Figure 3**), followed by research institutes (29%). The same two groups are taking the lead in France and Norway though in very different proportions (France: NGOs 85%; Norway: R.I. 88%). Often, there is collaboration between these two stakeholders in one or more stages of the projects. Only a small number (15%) of the North Sea projects is being coordinated by a collaborative effort, through government organisations or by individuals. NGOs as well as

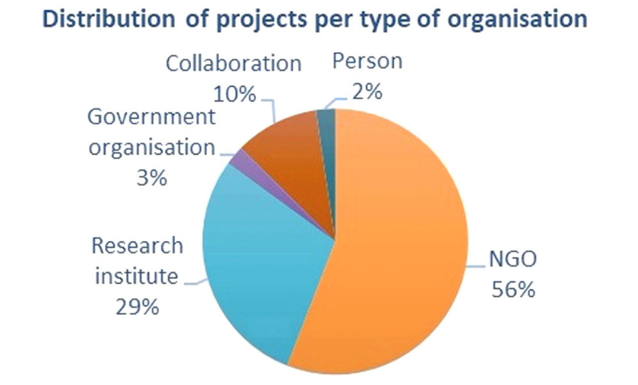

FIGURE 3 | Distribution of marine citizen science projects per type of organization in the North Sea (from van Hee et al., 2020).

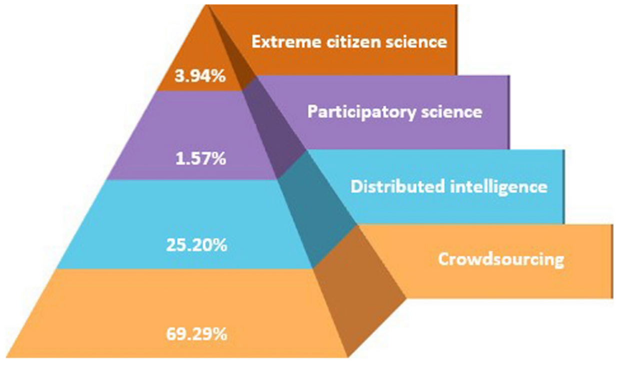

FIGURE 4 | Distribution of marine citizen science projects by types of participation in the North Sea (from van Hee et al., 2020).

research institutes have a focus on species-specific research (55%). Governmental organisations focus on pollution related topics and species research.

In terms of general aim, one can distinguish three major types of initiatives: "descriptive" (=purely collecting data), "performance oriented" (= monitoring and evaluation), and "composite" projects (= tackling important policy issues) (Lehtonen et al., 2016). All types of institutions in the North Sea area cover a mixture of those general aims. Governmental organisations have a slight preference for composite projects. Research institutes are more into the descriptive citizen science initiatives and NGOs have a slight preference for performance initiatives.

Types of Programme in Terms of Participation

Shum et al. (2012) and Haklay (2013) define four types of programmes in terms of the participation that is needed. "Crowdsourcing" requires the lowest level of participation. No knowledge on the subject is required, and citizens act merely as sensors often in the form of reporting observations "Distributed intelligence" requires more effort and a certain level of knowledge from the citizen scientist. "Participatory science" involves citizens in defining the problem, composing a method, and in data collection, while "extreme citizen science" pushes participants to interact in all the research steps, including data analysis. The level of participation obviously determines the number of existing projects. In the North Sea study (**Figure 4**), crowdsourcing is most frequent (69%), followed by distributed intelligence (25%). Two projects explored participatory science, and only five projects reached the most interactive level of extreme citizen science. This is in accordance with the expectations, as demonstrated with the citizen science pyramid: the higher the level of participation, the more effort needed from the citizen scientists (and from the organisers) and the less projects are found. The lowest level of involvement – crowdsourcing – requires least effort or knowledge in order to participate and therefore is most successful in terms of number of projects and participants.

The required time investment also influences the level of involvement. Currently, 72% of the North Sea projects and 78% of the Norwegian ones collect data in a continuous way (with no obligations). Projects that are collecting data in a continuous way, are often at a crowdsourcing level (73% in North Sea).

THE ROLE OF TECHNOLOGY IN MARINE CITIZEN SCIENCE. RECENT DEVELOPMENTS

The future of citizen science, including marine citizen science, is and will likely be inextricably linked to emerging technologies (**Figure 5**). Development of new technologies will increase the number of projects and participants, will ease the collection and analysis of data, and will facilitate the interaction between stakeholders (Thiel et al., 2014; Sandahl and Tøttrup, 2020). New technologies, such as mobile applications (Leeuw and Boss, 2018; Yang et al., 2018), wireless sensor networks (Benabbas et al., 2019), and online computer/video gaming (Lee et al., 2014; Koepnick et al., 2019), show great promise for advancing citizen science. Software developed for use on portable devices such as smartphones (Compas and Wade, 2018) and other mobile, web-enabled equipment (Seafarers et al., 2017) are already central in citizen science activities. Wireless sensor networks consist of spatially distributed, autonomous or semi-autonomous sensors that monitor georeferenced environmental conditions, such as physical, chemical and biological parameters, sound (Mukundarajan et al., 2018)[3], pollutants[4], vibration or motion. Emerging technologies have the potential to engage broad audiences, motivate volunteers, improve data collection, control data quality, corroborate model results, and increase the speed with which decisions can be made. The volume of data generated fits the big-data. Advances in AI and machine learning are also allowing for efficiency gains. Development of virtual forums and virtual meetings will ease the promotion, formation,

[3] https://portal.frogid.net.au/

[4] https://www.producthunt.com/posts/the-ocean-cleanup-plastic-survey

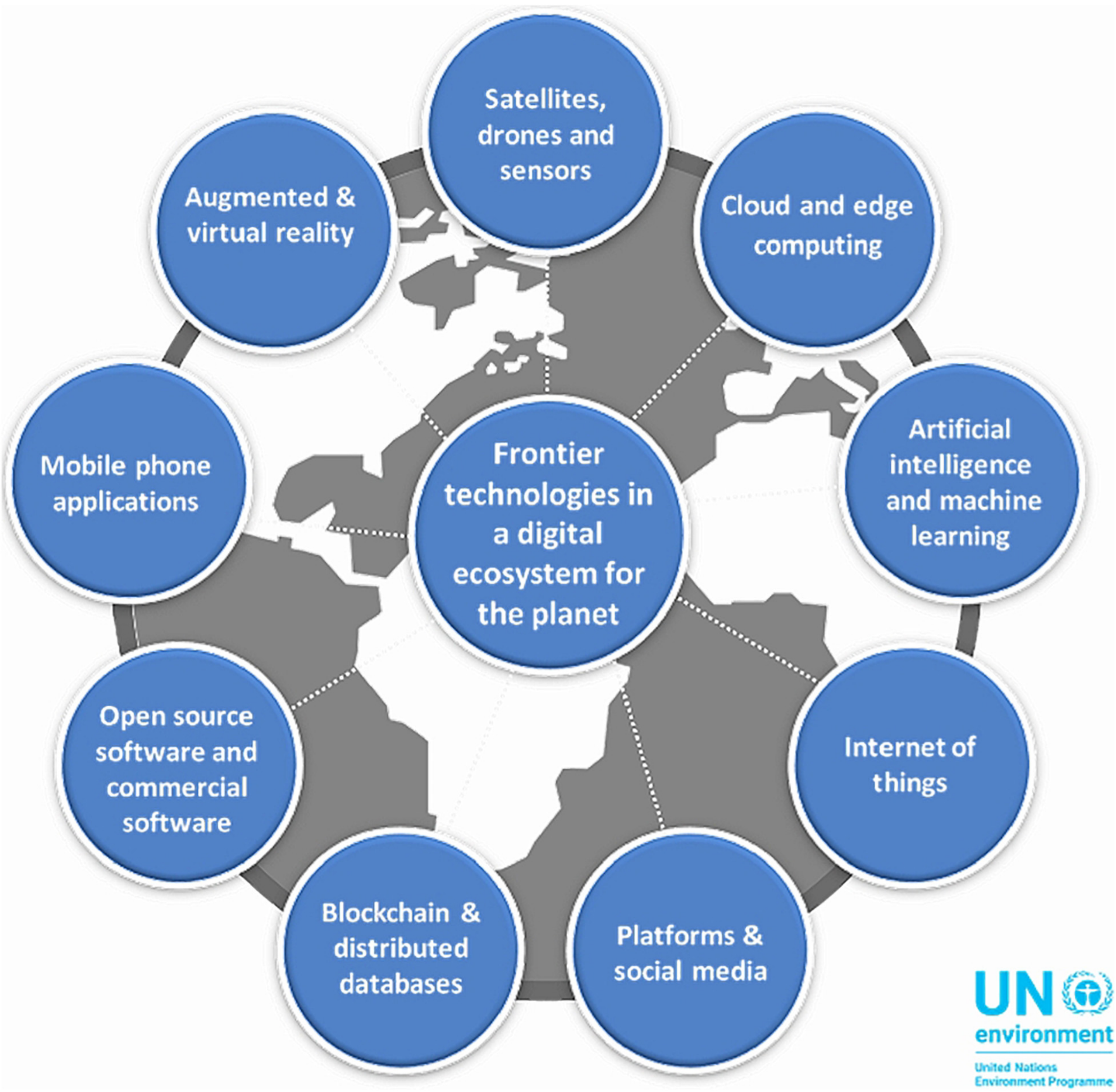

FIGURE 5 | Citizen science activities are embedded in the emerging digital technologies for the monitoring of natural resources and anthropogenic impact on the environment (from Jensen et al., 2019; Courtesy of UN Environment Programme).

quality checking, and analysis of data through the active contact between professional and citizen scientists.

Smartphones and Citizen Science

Technological innovations such as smartphone networked devices equipped with high resolution cameras have a strong potential for data collection, including large scale monitoring activities (i.e., Price et al., 2018), environmental alerts, etc. State of knowledge in the peer-reviewed literature related to the use of smartphone technologies is given in Andrachuk et al. (2019). Web-based and mobile applications contribute to data collection in the form of photographs, sound recordings or visual sightings but also to online tasks, such as transcription of datasheets or classification of media such as images, audio, and video. Metadata, such as position and time of measurement, can be automatically captured using embedded time and global positioning sensors, which are now standard in modern devices. The App BeachExplorer for example allows determination of coastline sightings (natural or anthropogenic) along the Wadden Sea (North Sea) coastline, by means of a visual guide. Beach sightings can be recorded including metadata and photographs. Another examples are the smartphone Apps "Meteomedusa" and "Infomedusa," which allow users to record user comments about the presence of jellyfish on the beaches of Italy (Zampardi et al., 2016) and southern Spain (Bellido et al., 2020).

A new use of smartphones is the possibility to transform them into light, compact and portable high resolution microscopes[5]

[5]https://www.kickstarter.com/projects/blips/diple-the-revolutionary-microscope-for-any-smartphone?lang=fr%20or%20www.smartmicrooptics.com/product/new-blips-labkit-2-explore-the-micro-world/

or their use for taxonomic[6] or acoustic mapping (Mukundarajan et al., 2018). A few oceanographic applications started to emerge recently. One of them is a mobile application called HydroColor that utilises a smartphone's camera and auxiliary sensors to measure the remote sensing reflectance of natural water bodies (Leeuw and Boss, 2018). HydroColor uses the smartphone's digital camera as a three-band radiometer. In the same direction, an add-on for portable spectroscopy and polarimetry (Burggraaff et al., 2020) is a low-cost instrument to mount on a mobile phone for citizen science measurements of aerosols and ocean colour.

High number of projects and applications for smartphones exist; most of them organised through platforms, community hubs for high-quality citizen science exchange, sharing knowledge, tools, training, and resources. An example is the site https://eu-citizen.science/offering to join in about 120 EU citizen science projects. The projects accessible on different platforms worldwide allow collecting a wide range of data using mobile phones. Citizens by mapping habitats and ecosystems; by determination of abundance and distribution of coastal and invasive species, by reports on water levels changes or by monitoring marine debris, in marine conservation projects demonstrate the scientific value of citizen monitoring (Harley et al., 2019). Using smartphone technologies citizen scientists increase the temporal and spatial data acquisition scales and play an important role in monitoring marine protected areas, coastlines and intertidal zones (Vye et al., 2020).

Complementarity of smartphone based marine citizen science data with scientific datasets has been shown. As an example, citizens can assess water colour by means of a Smartphone App (EyeOnWater). In the App, water colour (camera photo) is assigned to the so-called Forel Ule colour scale. The Forel Ule colour can be derived from ocean colour satellite instruments (van der Woerd et al., 2018) and is hence directly comparable to data derived by citizen scientists (Busch et al., 2016a,b). The corresponding Marine Data Repository of the EU project Citclops (finalised in 2015 and taken up by the EyeOnWater initiative) (Ceccaroni et al., 2020) has received about 10,500 entries by January 2021, which shows the use of smartphone technology in marine citizen science projects. This complementary use of citizen science datasets allows a successful integration of citizen science data to advance marine science.

Do It Yourself Sensors for Citizen Science

Even though the DIY approach is only at the dawn of its widespread use by citizens, it can constitute a powerful way to actively engage citizens in both the application and improvement of the sensors. Building a temperature sensor and connecting it to the smartphone can be realised with low costs and low technical knowledge. Quantifying a water parameter such as chlorophyll fluorescence, a proxy closely linked to phytoplankton abundance in the sea, can be achieved using self-assembled electronics in a mechanical housing printed on 3D-printers (Friedrichs et al., 2017). The scientific community proposed two inexpensive turbidimeters under DIY for citizen scientists. The turbidity tube (Myre and Shaw, 2006) is extremely simple to construct but is less precise than the Open Source Turbidimeter (Kelley et al., 2014). A simple hand-held DIY Secchi disc designed to measure the water clarity (or turbidity) of lake, estuarine and near shore regions is described in Brewin et al. (2019). The device is 3D printed. It is inexpensive, lightweight, easy to use from small watercraft and platforms, and accessible to a wide range of users. A low cost multi-sensor prototype for measuring chlorophyll *a* and Coloured Dissolved Organic Matter (CDOM) under water by using contact fluorescent imaging is proposed by Blockstein and Yadid-Pecht (2014). A simpler method proposed by Friedrichs et al. (2017) is the SmartFluo system based on a combination of a smartphone offering an intuitive operation interface and an adapter implying a cuvette holder, as well as a suitable illumination source. It is designed as DIY instrument well adapted for CS use.

A portable light-emitting-diode (LED) photometer has been developed to provide low-cost seawater pH measurements. The benefits of the new system include a simple "do-it-yourself" construction design, a hundredfold reduction in cost relative to benchtop spectrophotometric systems, routine calibration-free operation in the field, and precision and accuracy well suited to applications such as education, coastal zone monitoring (including citizen science programmes) and aquaculture (Yang et al., 2014).

High-resolution microplankton (20–200 microns) images (**Figure 6**) can be acquired by the PlanktoScope, an inexpensive imaging platform (Pollina et al., 2020). Its modular configuration is based on DIY hardware and open software. The control of the instrument is possible from any device able to access a browser through a WiFi connection and the image processing is based on a python-based library designed to handle large volumes of imaging data. The *In situ* Plankton Assemblage eXplorer (IPAX) enables the transition toward higher size spectra. It is an open-source low cost-imaging platform for zooplankton (>100 microns). It is a programmable instrument with LED illumination and a high resolution camera for *in situ* recording. Its field of view and focal depth are $50 \times 30 \times 5$ mm. It allows autonomous plankton survey (Lertvilai, 2020).

The DIY activity has the potential to aggregate multidisciplinary citizen know-how around signal acquisition and processing with rigorous data quality control. It may stimulate the move from simple data collection to hypotheses based projects.

Autonomous Unmanned Systems or Drones

In recent decades, autonomous unmanned systems (AUS) or drones, both aerial and submarine, have received increasingly significant attention due to their potential to enhance unmanned system intelligence, unmanned system performance, and efficiency. One of the key objectives of AUS systems is to realise a high degree of autonomy under dynamic, complex environments.

Recent advances in unmanned aerial vehicles (UAV) or aerial drones imagery, sensor quality/size, and geospatial image processing can enable UAVs to rapidly and continually monitor

[6]https://www.inaturalist.org

FIGURE 6 | Examples of Mediterranean microplankton imaged by PlanctonScope. PlanktonScope is an inexpensive imaging platform for citizen oceanography (Pollina et al., 2020) with a modular configuration based on do it yourself hardware and open software. The control of the instrument is possible from any device able to access a browser through a WiFi connection (Courtesy of EcoTaxa plankton imagedatabank; https://ecotaxa.obs-vlfr.fr/).

coral reefs and other coastal environments (Parsons et al., 2018; Merlino et al., 2020). Aerial drones can provide cost-effective monitoring of the environment at spatial and temporal resolutions that are appropriate to the scales of many ecologically relevant variables. Citizen scientists have used them to study El Niño, observe erosion, and monitor the behaviour of sea turtles and marine mammals (Hodgson et al., 2013). The advancements in aerial drone technology have revolutionised the production of aerial imagery. Aerial drones were used by citizen scientists to measure eelgrass meadow extent, patchiness, and dynamics through time on transects along the coast using Public Participation Geographic Information System (PPGIS)[7].

Citizen-science aerial drone surveys are a cost-effective method, which both engages local communities in management

[7]http://www.citizensciencegis.org

and delivers highly precise and accurate data for researchers and managers. This type of drones enable rapid surveying of beach volumes and therefore provide critical information for determining the dynamism of beaches. Pucino et al. (2021) documented this work undertaken by citizen scientists using a protocol made by Australian scientists. The results show that citizen scientists' data were of comparable accuracy to professionally acquired UAV datasets. Another example is the combination of citizen science observations, aerial drone photography and satellite imagery to document and analyse hurricane impacts in eastern Caribbean. Quantifying the impact of the hurricane event on landscape is an important critical step guiding restoration of ecosystem communities (Boger et al., 2020). Coastal habitats are the critical first line of defence from storm damage. It takes just a few hours to produce a high-resolution orthorectified mosaic from multiple individual aerial images taken by aerial drones equipped with associated flight control and image processing applications. In spring 2020 NASA released a new citizen science opportunity – a video game where players build a map of the world's coral reefs. Special "fluid lensing" cameras were mounted on drones to survey the seafloor. Just by playing their video game, NeMO-Net, volunteers help map the world's coral reefs[8]. Beside continuous amelioration of UAS, the next developments will include swarming methods usually inspired by nature, such as bird flocks or fish schools, to achieve complex common objectives through collaborative behaviours.

[8]www.nasa.gov/solve/Nemo-Net/

Unlike aerial drones the underwater or surface drones are not cost-effective and are only rarely used by non-professional scientists. Nevertheless, they have a strong educational potential. For example the project "Adopt a float"[9] is based on the idea that middle school classes adopt profiling Argo floats, to accompany their long-term data acquisition to better understand the marine environment and the scientific method while sharing with the scientists the discoveries in near real time Underwater drones will help discover things that are impossible to achieve using scuba diving. Typically, these drones are divided into two camps: remotely operated underwater vehicles (ROVs) and autonomous underwater vehicles (AUVs). ROVs are the devices that are now coming down into the consumer price range. Consumer ROVs today require a tether, or a cable that connects them to the remote control device. They generally come with lights and high-resolution cameras that can send photos and videos back to any device able to run a standard Web browser, such as a laptop or tablet computer[10].

Artificial Intelligence and Big Data Treatments

Artificial intelligence has become an integral part of our lives. Search engines, language translators, customer portals, diagnostic systems, manufacturing robots. The list of AI applications is long, but it is only at the beginning. No technological innovation has developed as rapidly as this branch of information technology in the last 10 years. However, the question if AI can contribute

[9]http://www.monoceanetmoi.com/web/index.php/en/adopt-a-float-project
[10]https://www.mpacollaborative.org/resources/rovprogram/

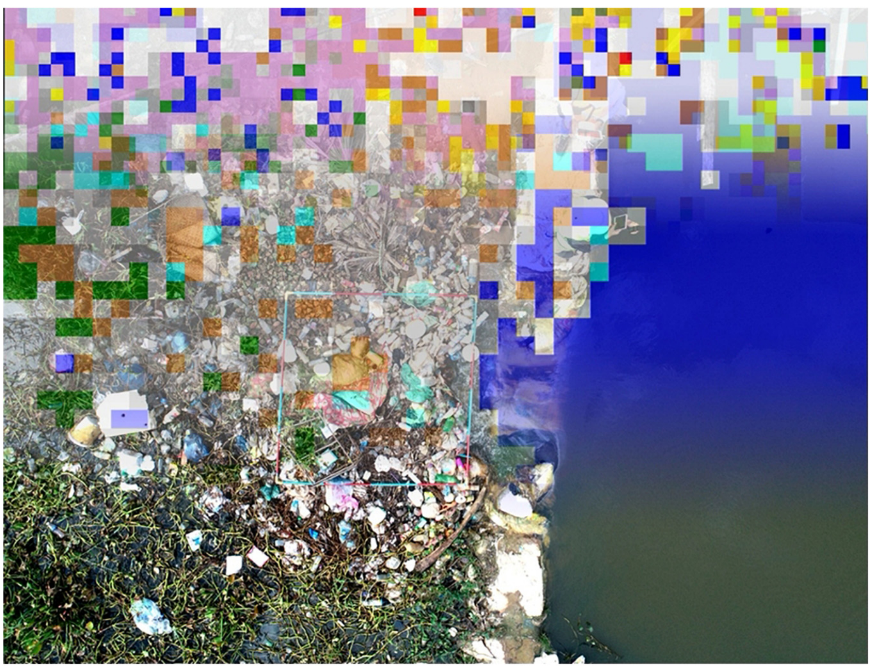

FIGURE 7 | Application of the APlastic algorithm, originally designed for UAV operations over plastic liter, from a citizen smartphone (Courtesy of DFKI-German Research Center for Artificial Intelligence).

to saving the (blue) planet is still to be answered. In a study published in 2018 by the World Economic Forum ("Harnessing Artificial Intelligence for the Earth"), the six most urgent challenges for the use of AI are identified: Climate change, biodiversity conservation, healthy oceans, water security, clean air, and resilience to extreme weather events and natural disasters. The utilisation of AI as an empowerment for citizens to monitor the marine realm and contribute to its protection is in its infancy but of highest potential, given the rapid development of this technology and its pervasiveness of our daily lives.

An example of AI-supported analysis of sensor data is the World Bank-funded initiative to collect plastic waste information over Asian rivers (Wolf et al., 2020). Research shows that more than 2/3 of the plastic waste in the ocean is discharged by just 20 rivers, most of it in Asia (Lebreton et al., 2017; Schmidt et al., 2017). Wolf et al. (2020) use multispectral image data of drone flights from Cambodia, the Philippines and Myanmar to determine both the amount and the composition of the debris using a two-step approach of artificial neural networks. The former is relevant for efficient waste disposal, while the detailed information on individual waste components (cups, food packaging, and transport containers) helps local authorities to identify the sources of plastic waste and to take countermeasures. "Closing the Loop" is the name of the appropriate initiative of the United Nations, which aims to enable the Southeast Asian ASEAN countries to tackle the problem of littered rivers, coasts and seas through technological innovations. With respect to the wider integration of citizens (beyond the broad availability of UAV platforms or drones), their algorithm is adaptable to smartphones, enabling direct applications (see **Figure 7**).

Artificial intelligence is above all a tool: designed to recognise patterns in complex data, to learn from this data, and to use what has been learned to achieve specific goals through flexible adaptation (Kaplan and Haenlein, 2019). It brings risks but also important opportunities for environmental protection and the transformation of our society toward ecological, social and economic sustainability. Integration of citizen science activities and AI may allow scientists to create and process larger volumes of data than possible with conventional methods (McClure et al., 2020). With the increasing capacity to collect big datasets, data processing may become a major bottleneck. Complementarity of citizen science and AI has the potential to maximise outcomes in ecological monitoring for scientists and conservation managers by analysis of big data sources (Ditria et al., 2020). Crowdsource projects, for example on the Zooniverse platform, can combine AI with image identification, classification, and validation by citizen scientists. AI based automated identification of sound or images is already used in conservation biology (Kwok, 2019). Future technological advances in the application of interconnected devices combined with citizen science may provide ecologists with management systems where continuous environmental information flows at high temporal resolution.

Social Media in Citizen Science Projects

By the end of 2020 there were 2.7 billion Facebook and 262 million Twitter users around the world. Europe has 387 million Facebook users[11]. Internet is a source of unprecedented amounts of diverse and accessible data, via webpages, social media, and various other platforms. Social media may significantly contribute to the development of Citizen Science by providing forums to discuss projects, share results and to feel part of a community, which they are contributing to. Digital data that are constantly created and stored in the digital realm may provide new understandings of ecological dynamics and mechanisms, in complement to traditional methods. A number of information is gathered through Facebook groups (Encarnação et al., 2021) such as observations of non-indigenous species at sea and on land (Bariche et al., 2018; Rahayu and Rodda, 2019; Azzurro and Tiralongo, 2020). Emergence of new data sources will require the use of search machines, new ways of data handling and dedicated methods to analyse them (Jarič et al., 2020).

CONCLUSION AND FUTURE PERSPECTIVES

This first analysis of the current state of marine and coastal citizen science in Europe is largely based on a review of the North Sea area with extensions added from surveys in Norway and France. A quantitative assessment of this kind is not available yet for all marine regions in Europe, but we consider, from the many existing initiatives in the Mediterranean basin for instance, that marine citizen science is omnipresent all over the continent, and holds a high and partly untapped potential.

An overall directory of existing marine citizen science projects in Europe is still missing and we strongly recommend developing such a directory in order to increase transparency and overview Citizen science can be a powerful tool in shaping an open science landscape in Europe.

Whereas today a majority of the citizen science projects is having a focus on life sciences and the study of species, new opportunities are present in the field of coastal morphology and protection, history, weather and climate, human health at the coast, etc. Also in terms of policy, marine and coastal citizen science is a promising and still undervalued format. It will help bridging the gap between researchers and the wider public and create higher ocean awareness.

Development of new technologies both instrumental and dematerialised shows great potential for advancing citizen science. Progress made in affordability and networking capacities allow for example citizen science activities in low-income countries. Data collection can now be carried out through a wide range of new instruments, devices and tools including mobile apps, interactive web services and DIY technologies. More than 5 billion privately owned smartphones with the possibility to deliver geocoded data are used on a daily basis all over the world.

Effective efforts are urgently required to improve the capacity of marine conservation as highlighted by the United Nations Decade of Ocean Science for Sustainable Development 2021–2030. Citizen science can

[11]https://www.omnicoreagency.com/facebook-statistics

act at large geographic scales as well. However, the methodological approaches necessary to ensure the quality of data provided by citizen science must evolve with technological development and the nature of projects.

The current demographics demonstrate that special attention should be paid to those that are, mostly unintentionally, excluded from citizen science activities (Haklay et al., 2018). Understanding of scientific reasoning helps evidence-based policy-making particularly nowadays when society has difficulties to discern between scientific facts and misinformation (Scheufele and Krause, 2019). Therefore efforts should be deployed to support citizen science activities in national and international research calls.

AUTHOR CONTRIBUTIONS

CG-S conceived the manuscript. JS led section "The Current State of Marine Citizen Science in Europe." OZ, GG, and JB led section "The Role of Technology in Marine Citizen Science. Recent Developments." All authors contributed to the article and approved the submitted version.

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Ocean Outreach in Australia: How a National Research Facility is Engaging with Community to Improve Scientific Literacy

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Marine systems across the globe are experiencing myriad pressures with consequences for their health, management and the industries and communities that depend on them. Critical to improved management of our oceans and coasts is effective education and communication that ultimately leads to improved societal value of the world's oceans. In Australia, the national scientific research agency, CSIRO, operates critical national research infrastructure such as the Marine National Facility (MNF), which also plays an important role in marine education, training and communication. The MNF Outreach Program seeks to strategically engage the community in marine science, identifying audience segments and developing programs, activities and content to meet their specific information needs. The program is structured around three specific audience segments: Purpose Seekers, Nurturers and Lifelong Learners. With both at-sea and shore-based activities and programs including the Indigenous Time at Sea Scholarship, CAPSTAN sea-training, Educator on Board, Floating Classroom, live ship-to-shore crosses and media and social media programming, the MNF Outreach program delivers meaningful engagement through experiential learning opportunities, rather than simply addressing knowledge deficits. As marine issues are varied and complex, marine communication and education approaches must be equally multifaceted, and a successful outreach program will have a spectrum of activities of varying resource intensity (such as cost, time and appropriately skilled personnel) which are matched to clear target audience segments. With increasing recognition of the importance of science communication in informing science literacy and policy, publicly funded national research facilities have an essential role to play by shifting from traditional research-only roles to also provide for targeted education and outreach.

Keywords: marine, outreach, education, training, ocean, engagement

INTRODUCTION

The global ocean covers 71% of the Earth surface and contains about 97% of the Earth's water (IPCC, 2019). It is our planet's largest ecosystem: stabilizing climate, storing carbon, producing oxygen, nurturing unimaginable biodiversity, and directly supporting human well-being through food, mineral, and energy resources as well as providing cultural and recreational services (United Nations, 2019). More than 40% of the global population lives within 200 km of the ocean (Visbeck, 2018). Yet marine systems across the globe are experiencing myriad pressures with consequences for their health, management and the industries and communities that depend on them.

The *United Nations Decade of Ocean Science for Sustainable Development 2021–30* (The Decade) seeks to strengthen the management of our ocean for the benefit of humanity by providing science, data and information to inform policy, and to generate scientific knowledge, underpinning infrastructure and partnerships. Critical to this capacity building is effective education and communication that ultimately leads to improved societal value of the ocean. There is a tremendous opportunity to connect ocean science more directly with societal actors by promoting integrated ocean observation and solution-oriented research agendas (Visbeck, 2018) and improving ocean literacy and education to modify social norms and behaviors (Claudet et al., 2020).

The Decade represents a key time to focus on the development of a globally coordinated, sustained, integrated and fit-for-purpose ocean observing system to support ocean science, assessment, prediction and the production of information that can inform policymakers and decision makers at all levels across local to global scales. It also provides space to more efficiently and widely promote ocean literacy as a key tool to engage society and to lever actions on the ground (Claudet et al., 2020), develop marine science research training that is more aligned with industry, government and societal needs (National Marine Science Committee, 2015) and engage more effectively with Indigenous knowledge systems.

The environment in which marine researchers operate today is increasingly diverse (female scientists represent on average 38% of the researchers in ocean science, about 10% higher than science overall), multidisciplinary (39% of ocean science facilities work across a broad range of issues) and resource intensive (numerous staff and costly equipment including ships, ocean installations and laboratories are distributed around the world comprising, for example, 784 marine stations, 325 research vessels, and more than 3,800 Argo floats) (UNESCO, 2017). Diversity in both people and discipline drives innovation and progression. However, to achieve a society that genuinely values the ocean, educates and trains expert marine practitioners and engages with a receptive community, national marine facilities need to shout about the quiet achievements of their research collaborators, communicate the impact they are generating and engage across all audience segments by developing programs, activities and content to meet the specific information needs of each.

THE AUSTRALIAN CONTEXT

Australia's marine environment is the third largest in the world, with an exclusive economic zone covering 10.2 million square kilometres (Australian Institute of Marine Science, 2018). With more than 70% of Australia's territory lying beneath the ocean (Australian Institute of Marine Science, 2018) it is home to a diverse and unique array of ecosystems and seascapes which are largely unexplored. Australian oceans are home to 11% of the world's known marine species, and support over 5,000 species of fish, and around 30% of the world's sharks and rays (Pink, 2010). The economic and conservation value of these waters is considerable as they contain valuable oil and gas fields and fisheries, as well as significant environmental assets such as the coral reefs, mangroves, sea grass beds, kelp forests and rocky reefs that are home to a diverse range of marine plants and animals (McCormick, 2020).

Australia's oceans directly and indirectly support commercial industries such as fisheries, shipping and resource extraction, and provide important revenue from recreational activities and tourism. The economic value of resources provided by the marine environment currently contributes approximately $50 billion per year to Australia's economy and is expected to increase to approximately $100 billion per year by 2025 (NMSP, 2015). Importantly, Australia's oceans and coasts also provide an estimated $25 billion worth of essential ecosystem services, such as carbon dioxide absorption, nutrient cycling and coastal protection (Evans et al., 2017). Together, this is referred to as the blue economy.

High-quality science, technology, engineering and mathematics (STEM) education is seen as critically important for Australia's current and future productivity, as well as for informed decision making and effective community, national and global citizenship (Australian Government, Department of Education, Skills and Employment, 2020). Yet there are numerous impediments to participation in STEM education and public engagement with STEM. Barriers to both the adoption and continuation of STEM education among young people include shortages of STEM qualified teachers, lack of investment in teacher professional development, challenges faced by STEM teachers to inspire their students, lack of support from school systems, limited opportunities for hands-on training of students, a dull curriculum, lack of awareness of career opportunities in STEM by both students and teachers, lack of career role models, and a perception that STEM subjects are too difficult (see Ejiwale, 2013 and Tytler et al., 2008 for reviews). At a broader level, there still exists a lack of knowledge and awareness about STEM and STEM professionals in the general community (Tytler et al., 2008) and effective public engagement is often hampered by issues such as an over-reliance on a small number of individuals, a lack of time and resources by STEM professionals, and a lack of systematic training and incentives for STEM professionals to participate in public outreach (Nature Neuroscience Editorial, 2009; Devonshire and Hathway, 2014).

In the marine sciences, Australia's National Marine Science Committee, an advisory body focused on promoting the nexus between high quality marine science and growth of the nation's blue economy, has developed the National Marine Science Plan 2015–2025 (the Plan) to provide a decadal focus on the investment and science required to fulfill the blue economy's potential. It outlines the research, infrastructure, skills, partnerships and investment that will drive the required changes over the next ten years. With challenges including marine sovereignty and security, energy security, food security, biodiversity conservation, sustainable urban coastal development, climate change adaptation and resources allocation, the Plan proposes a number of actions. These include improved decision-support tools, models and forecasts, industry and government partnerships, national collaborations, the application of cross disciplinary skills, the funding of national research vessels, increased exploration, mapping and monitoring, and the development of marine baselines and monitoring programs.

One of the Plan's key recommendations is to "develop marine science research training that is more quantitative, cross-disciplinary and congruent with industry and government needs." While there are many world-class tertiary offerings in the disciplines relevant to the blue economy, less than 3% of Australia's higher-degree research completions between 2009 and 2013 had an explicit marine science focus (NMSP 2015) and few universities have attempted to address the mismatch between the disciplinary focus of postgraduate training and industry demand (MacKeracher and Marsh, 2019) As such, Australia desperately needs to increase the participation rate and quality of students in a number of disciplines fundamental to marine science: mathematics, statistics, physics, chemistry and Information and Communication Technology (ICT) (MacKeracher and Marsh, 2019). The Plan also highlights the responsibility of the marine science community to facilitate a public engaged with marine issues.

Australia's national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), is committed to working to discover, enhance and sustain marine ecosystems, maximize the benefits from Australia's marine territory and, as one of the world's few publicly-funded research organisations, play an important role in science education and communication. CSIRO is also uniquely placed to invest in cultural knowledge and the participation of Aboriginal and Torres Strait Islander peoples in research. As inhabitants of the continent for over 65,000 years (Clarkson et al., 2017), Aboriginal and Torres Strait Islander peoples have enduring connections and rich knowledge of Australia's marine environments. Being the first marine scientists, Australia has much to gain by creating opportunities for genuine collaboration that leverages benefit from the fusion of Indigenous and western knowledge systems. In 2013, the Australian Government released its Indigenous Engagement with Science: Towards Deeper Understandings report (Expert Working Group on Indigenous Engagement with Science, 2013) to acknowledge the significant contributions that Aboriginal and Torres Strait Islander peoples have already made to the development of science in Australia, and the urgency to communicate the continued importance of engaging Aboriginal and Torres Strait Islander peoples in science to the scientific and broader Australian community. In response, CSIRO launched its Indigenous STEM Education Project in 2014, recognizing the important contributions that Aboriginal and Torres Strait Islander peoples can make to the future of STEM industries in Australia. Coupled with its Reconciliation Action Plan (Commonwealth Scientific and Industrial Research Organisation, 2016), CSIRO is committed to investment in Aboriginal and Torres Strait Islander cultural knowledge in relation to science, and the participation of Aboriginal and Torres Strait Islander peoples in Australia's research and innovation landscape. However, it remains the case that Aboriginal and Torres Strait Islander peoples are under-represented in STEM, particularly at the university level, where 0.5% of the Aboriginal and Torres Strait Islander population have a STEM qualification, compared to 5.2% of the non-Indigenous population (Office of the Chief Scientist. 2020).

CSIRO operates the Marine National Facility (MNF), the nation's only dedicated blue-water research capability. The MNF provides a blue-water research capability to the Australian research community and their international collaborators, comprised of the ocean class Research Vessel (RV) *Investigator;* advanced multidisciplinary scientific equipment and instrumentation; a repository of marine data collected since the MNF's inception in 1984; and operational and technical personnel with the expertize required to manage an ocean-going research platform and support vessel users. The research done on MNF voyages provides important information that supports evidence-based decision-making by government, industry and other stakeholders. MNF's strategic plan includes a focus on education and training and community engagement. Over the next decade the MNF will enhance education and training programs to include training the next generation of marine researchers and technicians in collaboration with other research/operational agencies and industries and increase their focus on communicating the impact of research delivered to better connect with Australians. The MNF is committed to delivering education and training activities that encourage and develop future generations of researchers and technicians, and help Australians understand the social, economic and environmental benefits of our oceans.

THE MARINE NATIONAL FACILITY OUTREACH PROGRAM

The MNF has sought to strategically engage with the community about marine science, identifying audience segments and developing programs, activities and content to meet their specific information needs (**Figure 1**). These activities are consolidated in the MNF Outreach Program, which focuses on increasing scientific literacy through experiential learning opportunities rather than simply addressing knowledge deficits. Commencing in 2016, the program is centered around three specific audience segments.

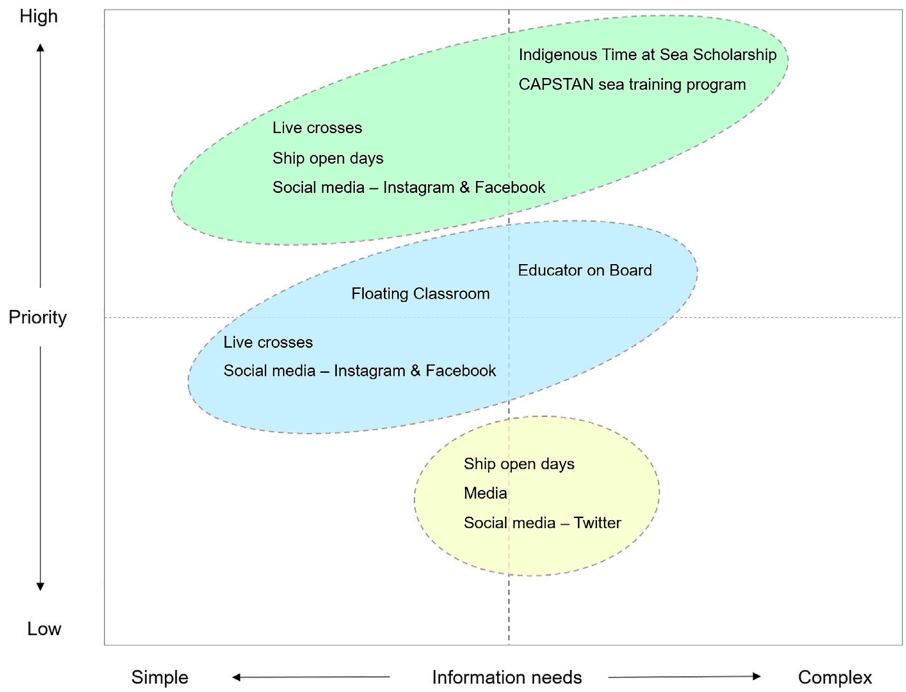

FIGURE 1 | Audience map of the MNF Outreach Program in context of target priority (*y*-axis) and information needs (*x*-axis). Audience segment groupings are represented by colored ellipses (green = Purpose Seekers, blue = Nurturers, yellow = Lifelong Learners).

Purpose Seekers

Purpose Seekers are the demographic of 13–34 year olds, encompassing Generation Z and Millennials. Purpose Seekers are typified by high school and tertiary students and those early in their career. This audience segment is seeking a future they can be excited about and have comparatively simple information needs. MNF offers several programs and activities targeted for this group (**Figure 1**).

Indigenous Time at Sea Scholarship

The Indigenous Time at Sea Scholarship (ITSS) offers Aboriginal and Torres Strait Islander university students a unique opportunity to gain experience on a world-class marine research vessel. ITSS brings students on board RV *Investigator* voyages to work alongside scientists and technicians to assist with research and gain valuable at-sea research experience. The program also aims to increase the diversity of the science teams on board voyages, which has multiple benefits.

Launched in September 2019, ITSS alumni report that the program increased their confidence and enthusiasm to study and pursue STEM careers (mean 10.0 ± 0.0 SD, $N = 2$), their motivation to engage with professionals from a range of STEM disciplines (mean 10.0 ± 0.0 SD, $N = 2$) and empowered them to encourage and inspire their peers at university and within their communities to pursue STEM studies (mean 9.0 ± 1.4 SD, $N = 2$). Following their involvement with the ITSS program, students have gone on to have their stories published in national media, featured as interviewees on national radio and television, and contributed to outreach activities in schools around the country thereby leveraging their experience and providing role models for other Indigenous and non-Indigenous students studying STEM.

CASE STUDY: INDIGENOUS TIME AT SEA SCHOLARSHIP SCHOLAR SOPHIE GILBEY

Alyawarr woman Sophie Gilbey was one of two students to be awarded the first Indigenous Time at Sea Scholarship. Sophie joined an 11 days voyage on RV *Investigator* studying the ocean and atmosphere of the Australian tropics and west coast between Darwin and Perth (**Figure 2**). On the voyage Sophie participated in research of plankton, sea birds and marine mammals, microplastics and meteorology. She learnt that there is a relationship with the ocean and everyday life that isn't always obvious and that it is far more complex than she realized; everything that humans do can have an impact on the ocean and as we rely on the ocean for food and regulating our climate, what we do to the oceans will ultimately affect us in the long run, it is more than just fishing and days at the beach. She firmly believes that her experience in the program has not only put her in a better position to share this message, but that she has built unique skills and is more employable as a result. Feedback from the voyage shows that other voyage participants benefited from having ITSS students like Sophie on board as she was able to share her unique experiences, perspectives and knowledge systems.

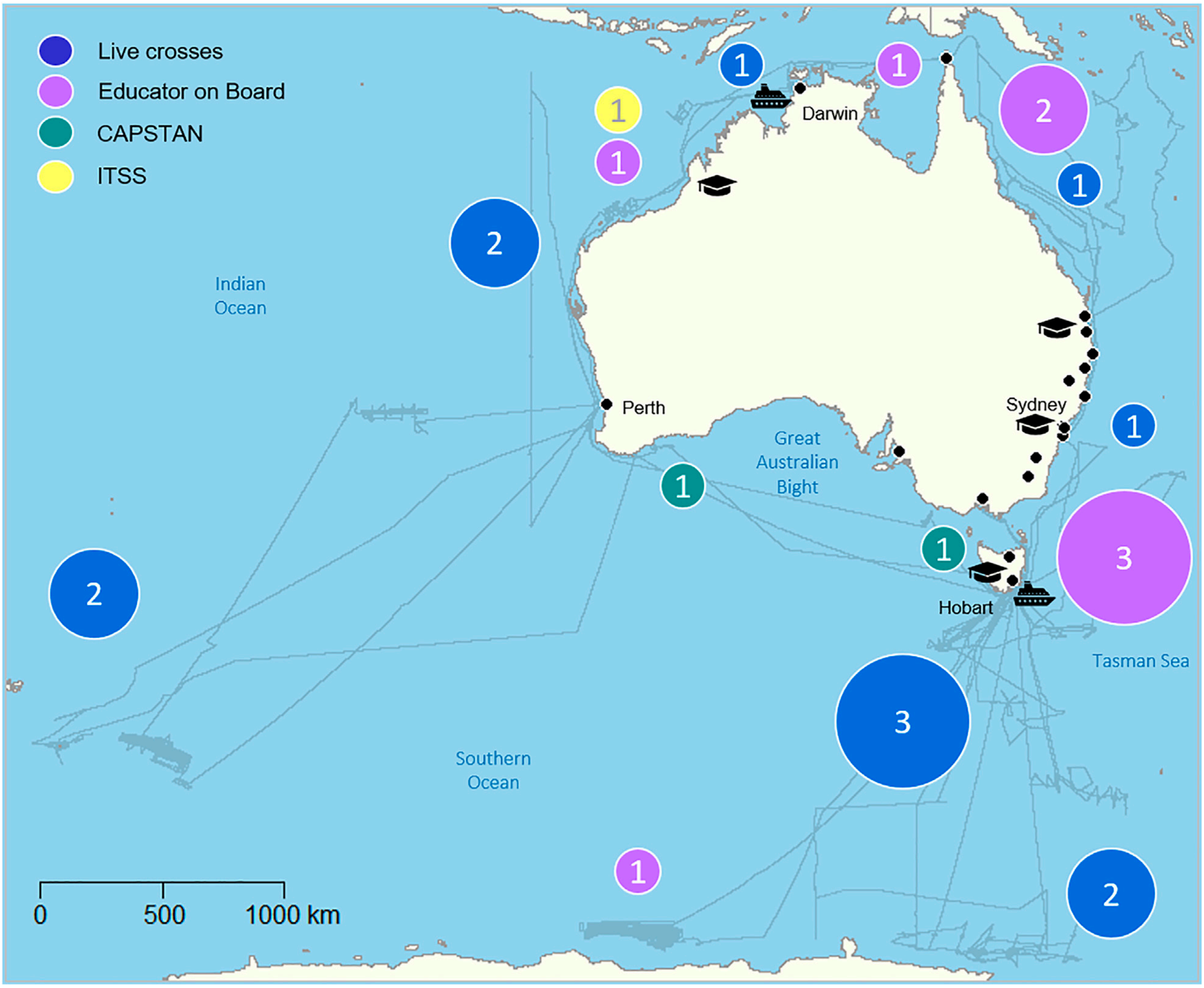

FIGURE 2 | Map of all activities undertaken as part of the MNF Outreach program 2016–20. Colored circles with numerical values represent the number of voyages hosting respective programs and activities grouped by geographic region. Voyage tracks are given in dark blue. Black circles indicate locations of audience for live ship linkups. Back pictograms represent ports that have hosted ship open days (ship) and *Floating Classrooms* (mortarboard).

Collaborative Australian Postgraduate Sea Training Alliance Network

The Collaborative Australian Postgraduate Sea Training Alliance Network (CAPSTAN) is a collective effort between MNF and Australian Universities to give tertiary students a hands-on-experience in blue water research. The program is building a network of marine researchers familiar with Australia's marine infrastructure, bringing students and marine experts from across Australia on a dedicated training voyage on RV *Investigator* each year (**Figure 2**). To date there have been 57 participants (students and trainers) from 17 Australian Universities in the CAPSTAN program who have spent 1,368 education days at sea (**Table 1A**). CAPSTAN focuses on an interdisciplinary approach to marine science with transferable skill development while promoting institutional, industrial, and generational knowledge transfer. Self-evaluations of learning conducted at the end of each CAPSTAN offering shows 93% of students improved their discipline specific skills (e.g. sediment descriptions, acoustic interpretations, sea life identification, data analysis) and 85% of students identified an improvement in their transferable skills (e.g. problem solving, critical thinking, teamwork, communication). An increase in their understanding of marine science career options was reported by 97% of student participants and all student and trainer participants indicated they would recommend the program to others. The factors the students identified as most important to facilitating their learning were related to the hands-on nature of the program, the environment on board created by the crew and the laboratory experience.

Students are not the only ones who benefit from their participation in the program, trainers also benefit from new collaborations and enhanced skills. Past trainers have written research proposals together and started projects with student

TABLE 1 | Summary statistics for the MNF Outreach Program for **(A)** at-sea programs 2016–2020, **(B)** on-shore activities 2016–2020 and **(C)** media and social media activities 2018–2020.

(A) At-sea programs

Program	Participants	Days at sea	Education days[a]	Number of universities/ schools	Gender diversity ratio (Male: Female:Other)
ITSS	2	11	22	2	0:2:0
CAPSTAN	57	24	648	17	22:35:0
Educator on board	17	150	273	17	10:7:0

(B) On-shore activities

Activity	Students/ teachers	Participants Public	Australian states/ Territories
Live crosses	3860	20 200	8
Floating classroom	271	–	4
Ship open days	1138	4733	2

(C) Media and social media

	Mainstream media		Social media snapshot	
	Items	Audience reach	Tweets	Impressions
2018/19	850+	10M+	600+	19M+
2019/20	1300+	10M+	450+	16M+

[a]*Education days = participants × voyage duration (days).*

participants from other institutions. Trainers frequently highlight that the program helped them broaden their research scope, improve their people management skills, and gain teaching experience. The ability to teach complicated concepts to students from diverse backgrounds and across career stages is a recurring theme in trainer feedback surveys. The upskilling of trainers is also beneficial to the MNF, ensuring a pipeline of experienced marine researchers with the relevant skills to form Australia's next generation of Chief Scientists and Principal Investigators.

CASE STUDY: COLLABORATIVE AUSTRALIAN POSTGRADUATE SEA TRAINING ALLIANCE NETWORK STUDENT ELISE TUURI

Flinders University then honors student Elise Tuuri was one of 20 students on the inaugural CAPSTAN voyage in 2017. The students met RV *Investigator* and a team of expert trainers from across Australia in Fremantle for a 12 days voyage across the Great Australian Bight to Hobart (**Figure 2**). A biologist by training, the voyage provided her first real dive into the breadth of disciplines involved in marine science. On the voyage she learned what it meant to live at sea, living and working within an isolated community that operates around the clock. She worked in small teams guided by the expert trainers on board to process sediment samples, identify and count marine mammals and sea birds, analyze water chemistry, and synthesize data to describe the biogeochemical processes at play in the Bremer Canyon region of the Great Australian Bight. While the region is named for the submarine canyon, for Elise and many of the other students on the voyage, the importance of that physical canyon in explaining why Bremer is known for whale watching was a level of interdisciplinary science she had not previously considered. When not busy in the laboratories, Elise learned to tie knots with the ship's crew, took a tour of the engine room, learned about life at sea through informal chats in the ship's mess or other common spaces, enjoyed being surrounded by the ocean, and reflected on the experience on the CAPSTAN blog. Now a Ph.D. student, Elise has returned to sea on RV *Investigator* as the Principal Investigator for multiple voyages with a micro-plastic focused project and she was slated to be a 2020 CAPSTAN trainer until the COVID-19 pandemic put plans on hold.

Live Crosses

Opportunities for our target audiences to get on board RV *Investigator* are limited. With advanced communication capabilities, the MNF supports activities that allow real-time engagement between RV *Investigator* and audiences around the world. Live crosses enable classrooms, lecture theaters, museums and social media users to experience a virtual tour or live Q&A session with RV *Investigator* while at sea anywhere in Australia's vast marine estate. While applicable to all three audience segments, live crosses are particularly targeted at Purpose Seekers, with 3860 students from every Australian state and territory having participated in a one-on-one live cross since 2016 (**Table 1B**).

Nurturers

Nurturers are aged 25–34 years and are typified by teachers and young parents. This audience segment is typified by concerns for a future where their children and students can thrive and, as a result, they have more complex information needs than Purpose Seekers (**Figure 1**).

Commonwealth Scientific and Industrial Research Organization Educator on Board

The CSIRO Educator on Board program is a professional learning opportunity for Australian STEM school teachers to participate in voyages on RV *Investigator*. On board, teachers assist scientists and technicians with research, enhance their STEM content knowledge, run outreach activities and develop teaching resources aligned with the Australian curriculum to be trialled in their own classroom and then shared with other teachers nation-wide. Educator on Board aims to support teacher professional development and provide students with a window on the real word application of STEM. Since launching in late 2017, 17 teachers have participated in eight voyages throughout the Australian marine estate (**Figure 2**), totalling 273 education days at sea (**Table 1A**). Quantitative feedback shows that the program increased participants' motivation (9.1 ± 0.9 SD, N = 17) and enthusiasm (8.7 ± 1.3 SD, N = 17) to teach STEM subjects and fostered connections with researchers that have endured post-voyage (9.3 ± 1.1 SD, N = 17). The program also increased teachers' understanding of marine careers (9.3 ± 0.9 SD, N = 17) and encouraged them to inspire their students to explore careers in the marine sector (9.3 ± 0.8 SD, N = 17).

CASE STUDY–EDUCATOR ON BOARD EMILY FEWSTER

Secondary distance education teacher Emily Fewster joined a 15 days voyage on RV *Investigator* as part of the Educator on Board program in December 2018/January 2019. During the voyage into the Tasman Sea (**Figure 2**). Emily worked alongside researchers to collect volcanic rocks from seamounts to help piece together the story of the breakup of Australia and Antarctica approximately thirty four million years ago. Emily worked as part of one of the science shifts, being tasked with sectioning rocks for analysis on a specialized diamond rock saw. As a result of her on-board learning Emily developed a four-part lesson with assessment about plate tectonics in the Australian-Antarctic context aligned with the curriculum (Fewster, 2019). Students learn about mantle plumes and their role in plate tectonics, the careers and technology used in geoscience, how to identify a range of rocks using a dichotomous key and how to identify plate movement based on the age of extinct volcanoes. The lessons feature contemporary research conducted on her voyage.

Floating Classroom

Floating Classroom provides an opportunity for Australian educators to use RV *Investigator's* laboratories and workspaces to deliver education and training activities while the ship is in port. The ship is available for Floating Classroom during port periods when operational requirements permit and is open to secondary and tertiary students. The program aims to increase understanding of how STEM is applied in the real world, seeking to inspire future generations of marine experts. To date, 271 students have participated in Floating Classrooms in Australian ports (**Table 1B**; **Figure 2**).

Lifelong Learners

The demographic of 35–55+ year olds encompassing Generation X and Baby Boomers are the Lifelong Learners. Lifelong Learners are typified by professionals and academics who are continually exploring and discovering new information through science. On average, they have complex information needs (**Figure 1**).

Ship Open Days

With at-sea operations taking RV *Investigator* to ports around Australia and overseas, the MNF seeks to use the vessel as a hub for community engagement events and capitalize on the invaluable tool the vessel offers to capture interest. The MNF makes the vessel accessible for tours and public events, with ship open days a major activity. Open days typically have tours for schools in the morning, followed by the public in the afternoon. During planning, priority is given to ports that the vessel has not visited before, therefore presenting opportunities to engage with new audiences.

Media and Social

The MNF, and CSIRO more broadly, adopt a strategic approach to media activities—both mainstream and social media—in recognition of the crucial role media plays in shaping public awareness and attitudes towards science. To maximize impact, we engage with target audiences through an objective-led framework that seeks to ensure communications are relevant (demonstrate our impact, focus on issues that matter), accessible (make content widely available, encourage content sharing) and appealing (authentic, credible and dynamic content). Audience analysis and segmentation is used to better understand target audience needs as well as identify likely business impact of effective messaging. This enables us to deliver purposeful content to identified and prioritized audience segments, which, in general, also has suitability for a wider audience. For each target audience the most effective channels to reach each is identified—whether that be social channels, mainstream media or a mixed model—as is the appropriate tone of voice and information complexity of content. Delivery of media activities is underpinned by the MNF's highly collaborative approach to all communications, as well as a strong emphasis on producing portable and engaging resources that encourage sharing. To support mainstream media engagement, the MNF offers media exposure and direct access to our research and researchers through both virtual and real experiences, including offering ship tours and opportunities to join research voyages. Through these activities, the MNF supports the wider objective of contributing towards national scientific literacy in order to help mobilize and develop the best talent for the benefit of Australia.

DISCUSSION

In Australia, participation in STEM subjects in schools is declining, with enrolments at their lowest level in twenty years (Kennedy et al., 2014). Overall performance in STEM subjects is also falling (PISA, 2018). This must improve if the country is to position itself to supply the skills required for future research and industries and is especially important for the marine sector, where a shortage of STEM skills is a major barrier to the sustainable development of Australia's blue economy (National Marine Science Committee, 2015). Key to addressing these deficits are programs that target school aged children, teachers, and students transferring into tertiary education, fostering the translation of students into STEM related occupations in academia, research and industry (Department of Industry, Science, Energy and Resources, 2017). Building marine science literacy in the general community also has an important role to play, as does building awareness of the unique blue-water research capability the MNF provides the Australian research community and their international colleagues to support oceanographic, geological, biological and atmospheric research.

Publicly funded research organisations have a responsibility to deliver emerging, innovative and creative marine science communication and education. Australia's national science research agency, the CSIRO, through the management of landmark research infrastructure like the MNF provides a nexus where the capability gaps and mismatches between the skills in demand by industry, and those taught in schools, the vocational education and training system and universities can be ameliorated. The impact of marine research training delivered in this way is only beginning to be realized, with 86% of surveyed students having participated in an RV *Investigator* voyage reporting that it would be impossible to gain the same quality of research experience and training elsewhere in Australia (Leonchuck et al., 2020). Students also report that they develop personal qualities including perseverance, adaptability and flexibility in the workplace from this training (Leonchuck et al., 2020). The development of these personal attributes is one of the key characteristics that private-sector employers seek in marine science sector students (see MacKeracher and Marsh, 2019) and demonstrates multi-dimensional impact from the MNF outreach and training experience.

A positive influence on the target audience is just one component of an effective outreach program. In an environment of limited funding and resources, it is important that, where practicable, our program also benefits from participants through a two-way exchange of knowledge, rather than a one-way delivery of information and services. The MNF Outreach Program has demonstrated the benefit of knowledge sharing with students and teachers, particularly in the Educator on Board and ITSS programs, to the collaborative marine science effort on voyages. This is especially important for nurturing the incorporation of traditional knowledge systems and Indigenous science into western marine science.

With an increasing recognition of the importance of the role of science communication in informing science literacy and policy, publicly funded national research facilities such as the MNF have an essential role to play by moving away from their traditional research-only roles to also provide for education and communication. Support for this expansion among the research community and facility users is crucial. To foster this support, the MNF now requires all applicants for sea time to address how components of the MNF Outreach Program could be incorporated into their research voyage, partnering with researchers to ensure that successful and meaningful outreach is an imbedded component of their use of the facility. The MNF Outreach Program demonstrates that publicly funded research facilities can and should play a key role in delivering training, education and communication objectives that build capacity and ultimately lead to improved societal value of environments such as the world's oceans. However, it is acknowledged that expansion of the scope of such national facilities does not come without difficulties.

An outreach program centered around a publicly owned, multi-disciplinary research vessel brings with it both opportunities and challenges. Recent welcomed increases to funding has seen RV *Investigator* operating at full capacity; up to 300 days per year at sea. While this presents increased opportunities for at-sea communication and education activities, port periods are necessarily compressed, reducing the ability to host higher volume ship open days and Floating Classrooms. The disruption to sea-going research and new protocols due to the COVID-19 pandemic have further accelerated the demand and uptake of remote, virtual engagement options. Early indications are that these activities have allowed us to reach newer and larger audience segments, suggesting an appetite for the expansion of novel virtual outreach options as a greater part of the MNF Outreach Program in future.

Across the globe marine issues are varied and complex, but the science recognizing the importance of a healthy ocean to life on Earth is well established. Improved societal value of the ocean leading to sustainable decision making can only be achieved when underpinned by effective education and communication. Just as marine issues are complex, marine communication and education needs and approaches must be equally multifaceted. At a regional level differences in marine environments, geography, information needs and socioeconomic circumstances result in multiple combinations of marine subjects and issues across a continuum of relevance to audiences. Designing and implementing an outreach program in this setting is difficult. Just as in other countries, marine issues in Australia are as varied as the environments encompassed by an area spanning the tropics to the pole, with a society spread between those living on the coast to those in the desert 2000 km from the ocean. The MNF Outreach Program demonstrates that these issues can be surmounted, at least in part, by having a spectrum of programs and activities of varying resource intensity which are matched to clear target audience segments.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: Data included in the article are program evaluation data, collected for the sole purpose of program development and improvement. Such data relate to the operation of programs and can only be presented in summary format as presented in the article. Requests to access these datasets should be directed to Ben.Arthur@csiro.au.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

BR, BA, MM, HM, BM and AA conceived the ideas and developed the program. BA, DR, BR, AA and MM wrote the paper.

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Citizen Science Driven Big Data Collection Requires Improved and Inclusive Societal Engagement

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Marine ecosystems are in a state of crisis worldwide due to anthropogenic stressors, exacerbated by generally diminished ocean literacy. In other sectors, big data and technological advances are opening our horizons towards improved knowledge and understanding. In the marine environment the opportunities afforded by big data and new technologies are limited by a lack of available empirical data on habitats, species, and their ecology. This limits our ability to manage these systems due to poor understanding of the processes driving loss and recovery. For improved chances of achieving sustainable marine systems, detailed local data is required that can be connected regionally and globally. Citizen Science (CS) is a potential tool for monitoring and conserving marine ecosystems, particularly in the case of shallow nearshore habitats, however, limited understanding exists as to the effectiveness of CS programmes in engaging the general public or their capacity to collect marine big data. This study aims to understand and identify pathways for improved engagement of citizen scientists. We investigated the motivations and barriers to engagement of participants in CS using two major global seagrass CS programmes. Programme participants were primarily researchers in seagrass science or similar fields which speak to a more general problem of exclusivity across CS. Altruistic motivations were demonstrated, whilst deterrence was associated with poor project organisation and a lack of awareness of specified systems and associated CS projects. Knowledge of seagrass ecosystems from existing participants was high and gains because of participation consequently minimal. For marine CS projects to support big data, we need to expand and diversify their current user base. We suggest enhanced outreach to stakeholders using cooperatively identified ecological questions, for example situated within the context of maintaining local ecosystem services. Dissemination of information should be completed with a variety of media types and should stress the potential for knowledge transfer, novel social interactions, and stewardship of local environments. Although our research confirms the potential for CS to foster enhanced collection of big data for improved marine conservation and management, we illustrate the need to improve and expand approaches to user engagement to reach required data targets.

Keywords: citizen science, big marine data, seagrass monitoring, inclusivity, community engagement

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INTRODUCTION

In an age of biodiversity loss and increasing anthropogenic stressors, there is a need for robust monitoring to log and prevent further loss (Driscoll et al., 2018). Within the marine environment, coastal ecosystems provide considerable ecosystem services including blue carbon sequestration, sediment stabilisation, water filtration, and high primary productivity (Barbier et al., 2011). However, despite well-documented ecosystem services, coastal environments are undergoing extensive degradation (Worm et al., 2006; Halpern et al., 2008). Environmental disturbances associated with poor coastal and catchment management, coastal development, climate change, and invasive species act to impede the ecosystem functioning of these habitats worldwide (Worm et al., 2006; Halpern et al., 2008). The ramifications of this degradation are severe, both for ecology and society, and require considerable effort to quantify and monitor losses and/or shifts in biodiversity to better identify potential remedial management or restoration approaches (Diaz et al., 2006; Friedman et al., 2020). Achieving monitoring to this end requires coordinated, large workforces and the creation of Big Data on suitably fine spatial and temporal scales (Duffy et al., 2019; Friedman et al., 2020).

Big Data can be thought of as data sets that are so large, and collected so rapidly, that they become difficult to analyse/manage with traditional means. Often these datasets are required to have a number of the *three V's*; volume, the quantity of data collected, velocity, the speed at which the data is collected, and variety, the variation in the data set (Kitchin and McArdle, 2016). Within seagrass research, these *V's* can translate to (i) adequate spatial resolution and replication (likely requiring extensive intra-country sites across a large number of countries exhibiting seagrass ecosystems), (ii) adequate temporal resolution (seasonal or sub-seasonal sampling to capture both inter- and intra-annual variation), and (iii) adequate detail in collected data (ideally containing density and morphology, taxonomy, and reproductive biology). Collecting data that fit these requirements on a global scale each year is beyond the scope of traditional field researchers, especially given the high degree of heterogeneity and logistical challenges associated with working in marine environments, and require novel approaches to meet these goals (Liu et al., 2017).

Currently, the majority of long-term monitoring projects occur annually (Duffy et al., 2019), and likely do not occur at the required spatial resolution for coordinated global monitoring. Further, current estimates of seagrass distributions based on collations of existing data are incomplete, showing large variations in mapping effort and tools used between countries (McKenzie et al., 2020). As such, although numerous projects exist which collect data on seagrass ecosystems across a number of countries worldwide, these efforts cannot yet be considered truly global and coordinated.

Participation in citizen science (CS), defined as involvement of members of the public in scientific studies without a formal scientific background (Thiel et al., 2014), is rising globally (Ellwood et al., 2017). CS projects are used extensively in ecology (Kullenberg and Kasperowski, 2016), where increased workforces can dramatically increase data collection potential both spatially and temporally while potentially reducing funding requirements (Kobori et al., 2016). As such, CS projects can be an attractive option for ecological studies requiring the collection of Big Data where minimal or no additional training is required and may be a suitable method to remedy existing data gaps in global seagrass distributions and promote a coordinated global monitoring system with the intent of establishing continued, truly global, data collection (Duffy et al., 2019).

Seagrasses are an ecologically important, evolutionarily unique, and spatially declining coastal habitat known for their considerable ecosystem services (Unsworth et al., 2018; McKenzie et al., 2021). Seagrasses have, like other coastal marine ecosystems, undergone substantial declines worldwide with rates of loss estimated at 7% per year (Waycott et al., 2009). Declines are linked to cumulative anthropogenic influences inducing reduced coastal water quality and accelerated habitat loss (Waycott et al., 2009; Short et al., 2011). Further, a lack of awareness of seagrass ecosystems in the general public leads to a lack of conservation effort and limited drive to reverse current losses (van Keulen et al., 2018). Potentially as a result of limited awareness and drive for conservation, seagrass CS projects exhibit limited participation and represent a small proportion of globally available CS projects (Jones et al., 2018).

Currently two seagrass CS projects exist which span large spatial scales and target considerable numbers of participants, namely Project Seagrass' SeagrassSpotter[1] and Seagrass-Watch[2]. Growth of both projects has been considerable since their conceptions (Jones et al., 2018) (a brief overview of the number of participants of each project is located in the "Materials and Methods" section).

Despite the recent growth of seagrass science and associated CS projects (Hind-Ozan and Jones, 2018) minimal work has been completed on the current demographics, the degree of inclusivity, the motivations, and potential barriers to participation. Complexities of participation in CS projects from a sociological perspective include participant-specific drivers for initial, sustained, and discontinued participation (Geoghegan et al., 2016). Research into individual projects can aid and review project design, facilitating greater participation in conservation and better integration of the needs of stakeholders and citizen scientists (Cigliano et al., 2015). Concordantly, by better understanding trends in participation, CS projects can increase their ability to produce scientifically robust Big Data at spatio-temporal scales adequate to support marine monitoring and management.

This study investigates participation in the above outlined seagrass CS projects *via* an online questionnaire designed to gauge the ability of the projects to collect and facilitate the further collection of marine Big Data. Specifically, the following aspects were investigated: (1) demographics of users, (2) drivers of participation in relation to (i) existing literature and (ii) participant-specific responses, (3) perceived gains associated with participation, (4) barriers present in (i) entry-level approaches e.g., SeagrassSpotter (ii) traditional participatory approaches e.g.,

[1]www.seagrassspotter.org
[2]www.seagrasswatch.org

Seagrass-Watch (iii) the use of mobile phones as monitoring tools, and (5) perceived knowledge gains *via* participation.

MATERIALS AND METHODS

A non-probability, convenience design was used to sample respondents (Etikan, 2016). Potential respondents were contacted *via* four seagrass orientated online groups (**Table 1**). Links to a questionnaire were included within contact media inviting the recipient to participate. Questionnaire creation and email dissemination processes were completed using Qualtrics software provided by the University of York. All responses were collected between 31/07/2018 and 5/09/2018. Any responses received after this date was not included in analyses.

Due to the non-probability approach taken throughout this study results herein are not representative of all CS volunteers (Van Selm and Jankowski, 2006). However, given that parties targeted for questionnaire dissemination were interested in seagrasses to some degree (**Table 1**), results can be considered representative of this group as a subpopulation (Etikan, 2016).

Ethical approval was obtained from the University of York Environment Department Ethics Committee. Informed consent to participate in the study was obtained from all participants prior to engagement in the questionnaire.

A conceptual framework of the questionnaire used throughout this study is contained in **Supplementary Material 1**. The questionnaire was comprised of five sections: Consent, SeagrassSpotter, Seagrass-Watch, Perceived Knowledge, and Demographic questions; utilised a range of question types: multiple choice, open ended, Likert-type and ranking exercises and was based on the design guidelines of Andrews et al. (2003).

SeagrassSpotter and Seagrass-Watch

SeagrassSpotter has accumulated around 3,050 sightings of 41 seagrass species from 95 countries or territories as of September 2020. Seagrass-Watch monitoring is established at 408 sites across 21 countries (Duffy et al., 2019). SeagrassSpotter and Seagrass-Watch each offer vastly different approaches to CS participation. Established in the United Kingdom in 2016, SeagrassSpotter presents an entry-level project utilising a primarily mobile interface; asking users to report sightings of seagrass *via* uploads of georeferenced photographs. Once submitted, additional information is supplied to accompany the uploaded photograph including phenology, associated fauna, and seagrass change (Jones et al., 2018). Conversely, Seagrass-Watch demonstrates a more traditional participatory approach, pairing citizen scientists with formally trained scientists to monitor trends in seagrass condition. Established in 1998 in Queensland (Australia), Seagrass-Watch has produced temporally long-term data which has proved a valuable tool for monitoring of established sites e.g., Great Barrier Reef, Queensland (McKenzie et al., 2012) and Singapore (McKenzie et al., 2017). To date, over 5,700 field site assessments have been conducted. Seagrass-Watch was founded as a community-based monitoring initiative but has evolved into the generally accepted methodology for seagrass monitoring utilised primarily by scientists; citizen scientists now contribute 40% of data when assisting scientists/environmental practitioners and 7% when operating without the supervision of a scientist (McKenzie et al., 2000, 2018).

Once consent was established, questionnaire respondents were asked if they were current users of SeagrassSpotter or participants of Seagrass-Watch. For respondents who answered “yes,” length and frequency of participation was established. Motivations for participation and perceived benefits were then queried based on factors outlined in Geoghegan et al. (2016). Attitudes towards the use of mobile phones as monitoring tools were then gauged in addition to respondents ranking a series of deterring concepts identified by Geoghegan et al. (2016). Deterrence was further conceptualised by asking explicitly what respondents thought would deter someone from participation in the project. Respondents were then asked whether they understood how their contribution to SeagrassSpotter helped to conserve seagrass ecosystems. Following this, current participants in Seagrass-Watch were questioned regarding their participation duration, frequency, motivations, and perceived barriers for that project specifically. Seagrass-Watch users were also asked whether they submitted their data to Seagrass-Watch HQ and to provide a reason if this was not the case. Respondents were then asked how they heard about the projects. Respondents who were not current users of a project were asked why this was the case and did not complete the respective project section.

Perceived Knowledge

Current users of either project were asked if they participated in additional CS projects, estimated their knowledge of seagrass ecosystems and their threats, and were asked to name threats to seagrasses in their area. Changes in perceived knowledge

TABLE 1 | Description and links to survey dissemination groups.

Group name	Description	Link
SeagrassSpotter Users	Email list comprised of current registered users of SeagrassSpotter	NA
Seagrass-Watch Users	Email list comprised of current registered users of Seagrass-Watch	NA
Murdoch University Seagrass Email Forum	Email forum comprised of people interested in seagrass ecosystems	http://lists.murdoch.edu.au/mailman/listinfo/seagrass_forum
United Kingdom Seagrass Network	Facebook group comprised of people interested in seagrass ecosystems – United Kingdom based	https://www.facebook.com/groups/545617545497309/

throughout participation within the respective projects were then gauged. Interaction with the marine environment and the nature of interaction with seagrasses were established to identify primary user groups.

Demographics

All participants were asked to answer additional optional questions regarding their demography, education, and profession.

Data Analysis

Analyses were completed within Qualtrics survey design software (Qualtrics, 2018) and R 3.5.0 (R Core Team, 2013) using the "*psych*" (Revelle, 2017) and "*ggplot2*" packages (Wickham and Chang, 2016). Participant responses were coded and summarised using simple frequencies and percentages. Where questions were open ended, responses underwent deductive content analysis (Hsieh and Shannon, 2005) to identify major themes. Concepts identified in the literature were used to create a categorisation matrix on which codes were based to reduce subjectivity (Elo and Kyngäs, 2008; Saunders et al., 2014; **Supplementary Material 2**).

Values from ranking and Likert-type scales were treated as interval data throughout analyses (Carifio and Perla, 2008). Thus, it was assumed that neighbouring items demonstrated an equal change in participant response regardless of position e.g., 1–2 on a scale was the same change as 4–5 (Sullivan and Artino, 2013). Perceived motivations and barriers to participation were summarised as frequencies per rank e.g., the number of times a concept was scored within each rank (1–10). Knowledge scores were summarised using means and standard deviations.

Cronbach's alpha was calculated as a measure of reliability for Likert-type scales investigating deterrence and knowledge (Cronbach, 1951). Alpha values were not calculated for questions ranking motivations as the survey design allowed participants to only choose concepts which applied, giving rise to incomplete data rows. Alpha coefficients suggested scales could be considered reliable as values were above accepted thresholds (SeagrassSpotter deterrence = 0.82 range 0.73–0.91, Seagrass-Watch deterrence = 0.88 range 0.79–0.96, knowledge = 0.94 range 0.9–0.97; all > 0.7). It should be noted that thresholds are guidelines and are application-specific (Lance et al., 2006) and that Cronbach's alpha values calculated here may be subject to inflation due to disproportionate increases in the number of covariates with an increasing number of scales analysed (Agbo, 2010). Further, Cronbach's alpha is not a measure of dimensionality (Trizano-Hermosilla and Alvarado, 2016). Multidimensionality was not assessed due to small sample sizes compared to those needed for robust assessment (Costello and Osborne, 2005) and should be expected here due to sociological complexities of concepts analysed (Jordan et al., 2011; Martin V. Y. et al., 2016). Influences of multidimensionality on conclusions drawn are, however, likely to be minimal given the study assessed multidimensional concepts influencing seagrass CS users, as opposed to attempting to identify unidimensional factors constituting each concept.

Comparisons of project participation, demographics, and perceptions of mobile devices were tested using Fisher's exact tests due to small observed values (Crawley, 2013). Within each project, perceived knowledge scores were correlated against participation duration and frequency using Spearman rank correlation coefficients (Murray, 2013) and were tested between demographics using Mann–Whitney *U* tests.

RESULTS

Demographics

Throughout the sample period, the questionnaire was completed 65 times; one respondent did not consent, thus valid $n = 64$. Respondents demonstrated similar demographics between SeagrassSpotter and Seagrass-Watch. Both projects demonstrated a variety of ages and countries of residence skewed toward the geographic origins of projects (**Table 2**). Gender of users was lightly skewed towards greater female participation (**Table 2**).

Samples of both projects were dominated by users who held undergraduate or postgraduate degrees (SeagrassSpotter: 90.9%, Seagrass-Watch: 87.5%). Degree levels varied between projects, with SeagrassSpotter users demonstrating a greater proportion of doctoral degrees (**Table 2**). Users primarily aligned their employment with educational and research professions, with the latter constituting an overwhelming proportion of current SeagrassSpotter users (80.5%). Around half of all respondents (48.4%) stated that their profession was directly involved with seagrass ecosystems. An almost equal proportion (47.5%) stated that their employment was affiliated with a university or equivalent organisation. Research was also a primary reason for interaction with seagrass ecosystems, although this was of lessened importance in Seagrass-Watch which showed a similar proportion of citizen scientists (**Table 2**). Generally, country of residence did not differ from the country in which users worked with seagrasses (73.3%).

Respondents demonstrated a loosely equal likelihood of participating in additional CS projects to those investigated (SeagrassSpotter: 40.9%, Seagrass-Watch: 50%, median number of additional projects = 2). Users of either project discovered the opportunity *via* social media, websites, and word of mouth (**Table 2**). Beach walking, SCUBA diving, monitoring, snorkelling, and other watersports comprised respondent's primary methods of interaction with the marine environment (**Table 3**).

Participation Length and Frequency

Current SeagrassSpotter users constituted a greater number of respondents than those of Seagrass-Watch, both projects, and non-users (**Table 4**); this variation was not significant statistically (Fisher's exact test $p > 0.05$). Length and frequency of participation also differed between projects (**Table 4**). Users of SeagrassSpotter reported short to medium (1–18 months) participation lengths whilst participation in Seagrass-Watch was comprised of longer durations (>5 years). Participation frequency was heavily skewed towards infrequent (once every few months) and incidental use in SeagrassSpotter, whilst Seagrass-Watch users demonstrated infrequent but regular or annual participation (**Table 4**).

TABLE 2 | Demographics of users of current SeagrassSpotter and Seagrass-Watch users summarised as frequency and valid percent (brackets).

		SeagrassSpotter	Seagrass-watch
Age	Under 18	0 (0)	0 (0)
	18–24	1 (4.6)	0 (0)
	25–34	8 (36.4)	2 (28.6)
	35–44	4 (18.2)	1 (14.3)
	45–54	4 (18.2)	1 (14.3)
	55–64	2 (9.1)	0 (0)
	65–74	2 (9.1)	2 (28.6)
	75–84	1 (4.6)	1 (14.3)
	85 or older	0 (0)	0 (0)
Gender*	Male	10 (45.5)	3 (42.9)
	Female	12 (54.6)	4 (57.1)
Education	Less than high school degree	0 (0)	0 (0)
	High school graduate	0 (0)	0 (0)
	College but no degree	2 (9.1)	1 (12.5)
	Bachelor's degree	7 (31.8)	4 (50)
	Master's degree	2 (9.1)	1 (12.5)
	Doctoral degree	11 (50)	2 (25)
	Professional degree	0 (0)	0 (0)
Employment*	Professional or technical	1 (4.8)	1 (16.7)
	Educational	2 (9.5)	2 (33.3)
	Retail trade	1 (4.8)	0 (0)
	Accommodation or food	1 (4.8)	0 (0)
	Arts, entertainment, recreation	1 (4.8)	0 (0)
	Researcher/scientist	15 (71.4)	2 (33.3)
	Unclassified	0 (0)	1 (16.7)
Involvement with seagrasses	Research (Academic/University)	11 (50)	1 (12.5)
	Research (NGO or equivalent)	2 (9.1)	3 (37.5)
	Government work	1 (4.6)	0 (0)
	Citizen Scientists	4 (18.2)	3 (37.5)
	Other: student, teacher, interested party	4 (18.2)	1 (12.5)
How did you hear about the project?	Word of mouth	6 (27.3)	3 (37.5)
	Online	4 (18.2)	1 (12.5)
	Social media	7 (31.8)	0 (0)
	Print media	0 (0)	1 (12.5)
	Other: profession, conference, volunteer group	5 (22.7)	3 (37.5)
Country of residence*	Australia	7 (24.1)	7 (43.7)
	Finland	2 (6.9)	1 (6.25)
	Germany	1 (3.4)	1 (6.25)
	Greece	1 (3.4)	0 (0)
	Japan	2 (6.9)	1 (6.25)
	Netherlands	1 (3.4)	0 (0)
	Philippines	1 (3.4)	2 (12.5)
	South Africa	1 (3.4)	0 (0)
	Sri Lanka	1 (3.4)	0 (0)
	Timor-Leste	1 (3.4)	1 (6.25)
	Thailand	0 (0)	1 (6.25)
	United Kingdom	8 (27.6)	1 (6.25)
	United States	3 (10.3)	0 (0)
	Vanuatu	0 (0)	1 (6.25)

**Results shown represent options with tallied responses only.*

The majority of Seagrass-Watch users submitted their data to Seagrass-Watch HQ (**Table 5**). Reasons for non-submission included taking part as a larger organisation or group, utilising adapted Seagrass-Watch methods but not taking part in Seagrass-Watch surveys specifically, and data compatibility or submission issues (**Table 5**).

TABLE 3 | Respondent's primary methods of interaction with the marine environment.

Code	Frequency and valid percent
Beach Walking	20 (24.1)
SCUBA Diving	12 (14.5)
Monitoring or surveys	12 (14.5)
Snorkelling	11 (13.3)
Watersports (sailing, kayaking etc.)	11 (13.3)
Swimming	8 (9.6)
Fishing	4 (4.8)
Beach cleans	1 (1.2)
Other: cycling, comments on the frequency of interaction	4 (4.8)

Motivations, Benefits, and Barriers to Participation

Motivations for participation were similar between seagrass CS projects although the relative importance of each concept differed (**Figure 1**). SeagrassSpotter users were primarily driven by contributing to scientific knowledge, helping wildlife (both in general and area-specific contexts), and by sharing their knowledge with others. Lesser motivations included learning something new or developing new skills (**Figure 1**). Seagrass-Watch users, however, were primarily motivated by meeting people and taking part for fun, in addition to influences of contributing to scientific knowledge and helping wildlife. Seagrass-Watch users also attributed further motivation to progressing their careers, because another person wanted them to, to spend time outdoors, to learn something new, and as a form of exercise (**Figure 1**).

Respondents did not perceive that their motivations had changed over time (**Table 6**) citing considerable previous monitoring of seagrasses, and a view that their actions can protect the environment more generally as contributing factors. Respondents that reported a change cited development within the project, attending conferences, and involving the local community as drivers of change.

Respondents reported a range of benefits associated with participation in SeagrassSpotter including increases in knowledge, a sense of contribution to science and the environment more generally and sharing knowledge with other users. Secondary benefits included using SeagrassSpotter as a record of sightings, developing social connections, spending time outdoors, and learning new skills (**Table 6**).

As with motivations for participation, deterring concepts were similar between projects (**Figure 1**). Respondents highlighted poor feedback, communication, disorganisation, a lack of impact or output, personal circumstances and underappreciation as deterring concepts. Seagrass-Watch users stated formal training and funding issues as additional project-specific barriers and generally reported higher deterrence scores than SeagrassSpotter users (**Figure 1**).

Non-users of seagrass CS projects reported similar deterring concepts to current participants (**Table 7**), citing personal circumstance as the primary driver of non-participation. Non-users of both projects highlighted a lack of awareness of the opportunity to participate, in addition to project-specific concepts of not downloading the SeagrassSpotter app and a

TABLE 4 | Variation in the number of participants, participation length and frequency of focal seagrass citizen science projects.

		Do you currently take part in SeagrassSpotter?		
		Yes	No	
Do you currently take part in Seagrass-Watch?	Yes	8	8	
	No	22	25	

	SeagrassSpotter		Seagrass-watch	
Length†	1–4 months	13 (43.3)	1–6 months	0 (0)
	5–8 months	2 (6.7)	7–12 months	3 (18.8)
	9–12 months	6 (20)	1–2 years	1 (6.3)
	13–18 months	3 (10)	3–4 years	2 (12.5)
	Greater than 18 months	2 (6.7)	Greater than 5 years	8 (50)
	Can't remember	4 (13.3)	Can't remember	2 (12.5)
Frequency†	More than once a week	0 (0)	More than once a week	0 (0)
	Once a week	0 (0)	Once a week	1 (6.3)
	A few times a month	1 (3.3)	A few times a month	1 (6.3)
	Once a month	0 (0)	Once a month	0 (0)
	Once every few months	8 (26.7)	Once every few months	4 (25)
	Incidentally	17 (56.7)	Quarterly	4 (25)
	Once a year	3 (10)	Once a year	2 (12.5)
	Less often	0 (0)	Less often	2 (12.5)
	Not sure	1 (3.3)	Not sure	2 (12.5)

† *Time periods are specific to either project based on the period they have been available and participation style.*

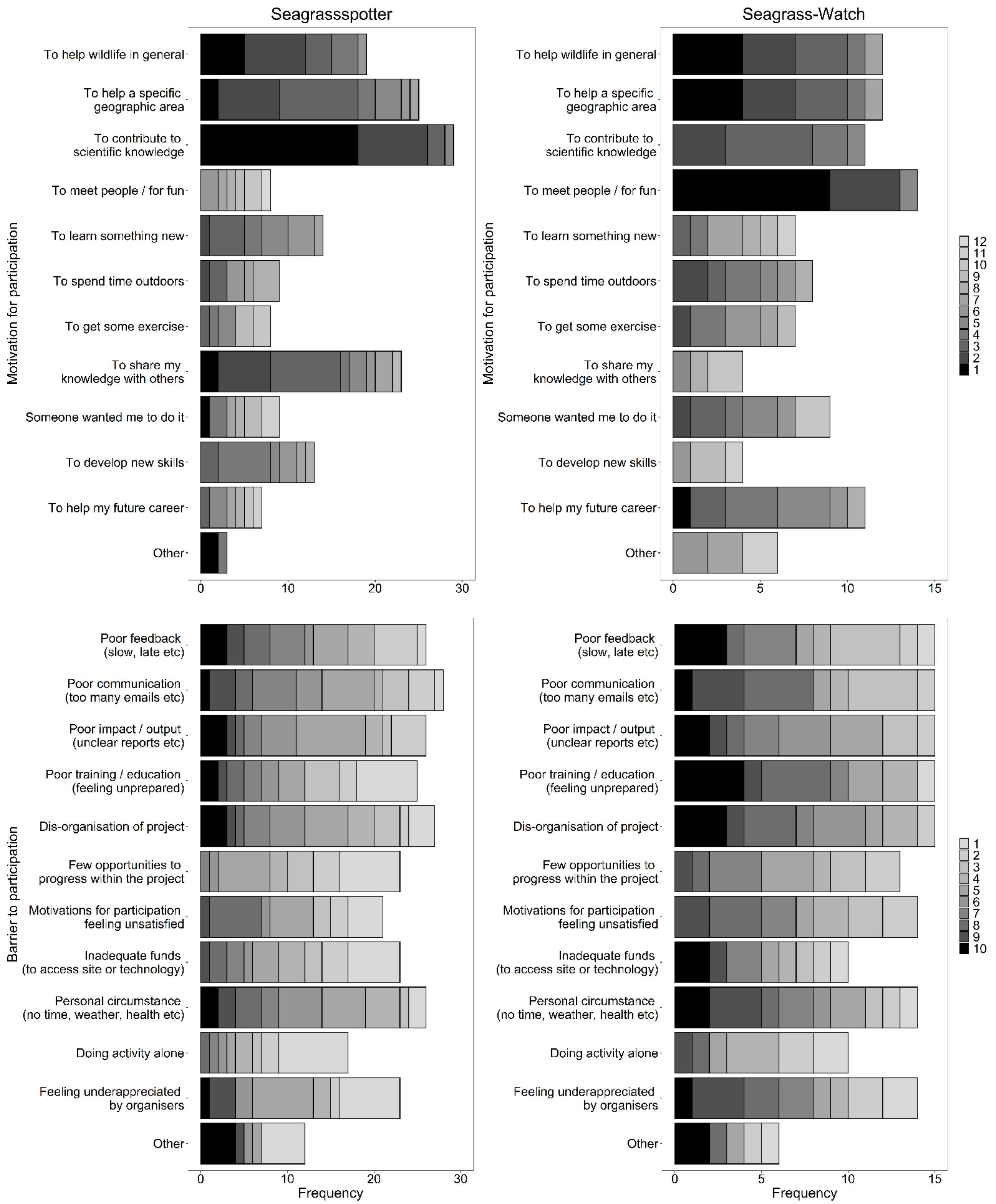

FIGURE 1 | Frequencies of motivations (upper) and barriers (lower) to participation in SeagrassSpotter **(left)** and Seagrass-Watch **(right)**. Colour gradient indicative of the level of motivation/deterrence where darker colours represent higher scoring in ranking or Likert type questions. Note the change in key for upper (1 = most motivating and 12 = least motivating) and lower (10 = most deterring and 1 = least deterring) plots.

TABLE 5 | Proportion of Seagrass-Watch users who submit their data to Seagrass-Watch HQ and reasons for non-submission.

		Data submitted to Seagrass-watch HQ?	
Frequency and valid percent		Yes 9 (60)	No 6 (40)
Reason for non-submission	**Code**	**Frequency and valid percent**	**Example comment**
	Organisation submits the data	2 (28.6)	*"Not me personally, but my organisation does"*
	Methods have been simplified	1 (14.3)	*". . . we use the Seagrass-Watch method as a basis but have simplified it for use with local volunteers"*
	Unsure whether the organisation submits the data	1 (14.3)	*"(data) goes to our local seagrass survey organisers, and we aren't sure if they are still organised to do anything with it"*
	Data not compatible	1 (14.3)	*"Our data is not compatible to the system in Queensland"*
	Participated as a group	1 (14.3)	*"Took part in the survey as part of a group"*
	Did not take part fully	1 (14.3)	*"I have not really taken part in Seagrass-Watch"*

lack of availability of Seagrass-Watch programmes local to them (**Table 7**).

Technology and Mobile Phones

SeagrassSpotter users demonstrated positivity towards mobile phones as conservation tools (**Table 8**), attitudes were not influenced by participant age or country of residence (Fisher's exact test, $p > 0.05$).

When asked what would deter them from continued participation, SeagrassSpotter users cited an overly complex design, lack of interest, poor mobile reception/Wi-Fi, nervousness over submitting incorrect data and a perceived lack of impact as primary factors (**Table 8**). Concerns were also raised by two respondents regarding security and use of participant personal data. Concerns over mobile reception/Wi-Fi were also raised by respondents when barriers to the use of mobile phones were gauged specifically. Concerns regarding a lack of access and level of comfort when using mobile devices were also raised. Despite this, most respondents perceived no additional barriers *via* mobile phone utilisation, instead citing ease of access, technological benefits and the potential for wide geographical spread as supporting their implementation (**Table 8**).

Perceived Knowledge of Seagrass Ecosystems

Generally, respondents reported considerable knowledge of seagrass ecosystems and their threats, mean knowledge of seagrass: 8.09 (±2.18), 7.63 (±1.77), 7.13 (±2.23), mean knowledge of threats: 8.41 (±1.56), 7.38 (±1.85), 7.25 (±2.12) for participants of SeagrassSpotter, Seagrass-Watch, and both projects respectively. Perceived knowledge scores did not differ significantly with the project users participated in (Mann–Whitney *U* test, $p > 0.05$). When the nature of interaction with seagrasses was analysed within a project-specific context (**Figure 2**), only SeagrassSpotter users demonstrated a significant change (Mann–Whitney *U* test, Knowledge of seagrass: $p = 0.006$, df = 4, $X^2 = 14.37$, Knowledge of threats: $p = 0.008$, df = 4, $X^2 = 13.81$), other projects did not produce significant results (Mann–Whitney *U* test, $p > 0.05$). Users who interacted with seagrasses as part of academic research or government work reported higher scores than citizen scientists and those with "other" interactions. Scores reported by non-governmental organisation researchers fluctuated considerably between projects (**Figure 2**). When gauged, perceived changes in knowledge throughout participation varied substantially between projects (**Table 9**). Reasons for perceived changes were similar between projects with respondents citing knowledge increases concerning training and methodologies, ecology behind observed trends, and knowledge gained from attending events (**Table 9**). Location-specific knowledge, greater environmental intervention, and wider ecological knowledge were cited as additional gains in SeagrassSpotter and Seagrass-Watch, respectively (**Table 9**). Perceived knowledge scores did not correlate with project-specific participation and frequency (Spearman's rank correlation, $p > 0.05$ throughout).

SeagrassSpotter users stated that they knew how their contribution helped to conserve seagrass ecosystems (**Table 10**). Perceived roles of contributions discussed increasing data coverage of seagrasses, references to data being used as preliminary work for more complex studies, and increasing awareness of seagrass ecosystems generally (**Table 10**).

Seagrass CS users identified a range of threats to seagrass ecosystems (**Table 11**). Salient themes throughout responses included references to physical damage, coastal development, changes to water quality, and climate change (**Table 11**).

DISCUSSION

Citizen science has been highlighted as a potential tool for improving the collection of Big Data in marine science through wide involvement of the general public, particularly in poorly mapped and poorly understood ecosystems such as seagrass meadows. Here we demonstrate that in the case of seagrass systems, the use of CS, although assisting with management and conservation, is largely ineffective at collecting

TABLE 6 | Perceived changes in motivations and benefits to participation in seagrass citizen science projects.

Do you think your motivations have changed over the period of participation?		SeagrassSpotter		Seagrass-watch	
		Yes	No	Yes	No
		3 (10)	27 (90)	3 (18.6)	13 (81.3)
Reason behind response	**Code**	**Frequency and valid percent**	**Example comment**		
Seagrass Spotter Perceived change	Involved the local community	1 (10)	*"Although I started doing it for work, I ended up getting a group of local kids to do it with me and it ended up being a great way to get them involved in marine conservation"*		
No perceived change	Long term monitoring/prior work	6 (60)	*"I work with seagrass and other algae before and after joining SeagrassSpotter"*		
	Protect the environment	2 (20)	*"I still believe the project can help protect the environment"*		
	Other: stated no change	1 (10)			
Seagrass-Watch Perceived change	Progression within the project	1 (16.7)	*"At the beginning I was a new volunteer, now I have been part of the program since 1998 and am [a] coordinator. We have a 20-year dataset, so I am very motivated to keep it going."*		
	Attend conferences	1 (16.7)	*"I am now passionate for seagrass in W.A. and regularly attend international seagrass conferences"*		
No perceived change	Long term monitoring	2 (33.3)	*"I have been monitoring as part of a long-term project, at one area (for) more than 9 years now"*		
	Prior research involvement	1 (16.7)	*"I am doing research in seagrass before and seagrasses are underappreciated in research"*		
	Other: stated no change	1 (16.7)			
Benefits of participation†	Knowledge increase	13 (35.2)	*"I support anything that involves education about ecosystems, the environment and [the] world in general. The more I understand about this topic the more I can do things to change the situation…"*		
	Contribution to science	9 (24.3)	*"Feeling that I contribute to science and the environment…"*		
	Sharing knowledge	7 (18.9)	*"I can share my knowledge with others and also profit from the knowledge others have already gathered"*		
	Record of sightings	3 (8.1)	*"Get to have a record of my sightings that I can access"*		
	Social Connections	2 (5.4)	*"SeagrassSpotter provides a connection with a network of people working my field of research"*		
	Spend time outdoors	2 (5.4)	*"Looking at our current sites and venturing into other sites where we think seagrass may be"*		
	Learning new skills	1 (2.7)	*"…learning concepts…learning more about a different environment and how to protect it"*		

†*Current Seagrass-Watch users were not asked how they thought they benefited from participation.*

Big Data as it is not currently reaching out effectively to the wider population, nor is it engaging the general public in understanding an underappreciated and largely unknown ecosystem. As a result of this limited outreach, seagrass CS projects in their current form fall short of the spatial and temporal resolutions and work forces required to globally monitor and manage this important ecosystem. Results outlined provide valuable insight into participation and knowledge transfer in SeagrassSpotter and Seagrass-Watch and represent the first known attempt to quantify such concepts in a seagrass-specific context.

Demographics and Participation

Countries that participated in seagrass CS projects were concordant with the variation in marine CS projects worldwide, with enhanced uptake in Europe, Australia, and United States Thiel et al. (2014). Increased participation in the United Kingdom and Australia is likely due to increased awareness of SeagrassSpotter and Seagrass-Watch in their home countries. Participating countries are also concordant with previous work summarising the demographics of existing seagrass research groups (Hind-Ozan and Jones, 2018). Similarly, users of both projects primarily cited "research" as a rationale

TABLE 7 | Perceived barriers to participation in seagrass citizen science projects from non-users.

Barriers to participation	Code	Frequency and valid percent	Example comment
SeagrassSpotter Non-users	Personal circumstance	13 (39.4)	*"not finding the time" "relocation to a part of the country that is inland"*
	Lack of awareness	10 (30.3)	*"Didn't realise it was a thing before this questionnaire"*
	Do not have the app downloaded	4 (12.1)	*"Have not yet installed the app…"*
	Other: lack of ID skills, species not available on the app	6 (18.2)	
Seagrass-Watch Non-users	Personal circumstance	24 (47.1)	*"I had no available time to lately, but I want to do more"*
	Lack of awareness	15 (29.4)	*"I've never heard of it"*
	Lack of programme availability	8 (16.7)	*"None organised locally, and no time to organise one myself"*
	Other: respondent unsure	4 (7.8)	

for interaction with seagrass ecosystems and participation in seagrass CS generally (**Table 2**). Increased participation, both in terms of geographic location and profession, was thus associated with users who were already aware of these projects through their professions. Within these user groups, length and frequency of participation was concordant with the length of time the project had been available (Jones et al., 2018) and how the project was designed, either incidental (SeagrassSpotter) or structured (Seagrass-Watch) (McKenzie et al., 2001).

Motivation and Deterrence

Users of both projects cited altruistic and environmentally positive concepts, knowledge development and social interactions as motivations and benefits of participation (**Table 6**). Altruism is frequent within environmental CS and indicates a drive to protect the environment for the good of others (Schwartz et al., 2012) and can be achieved *via* personal actions and by contributing to science, which is viewed as beneficial (Martin V. et al., 2016). Motivation by attainment and sharing of knowledge is also common (Rotman et al., 2014), with increased knowledge associated with an increase in environmentally positive behaviours (Bela et al., 2016). Minimal changes in motivations throughout participation (**Table 6**), also support the idea that users are altruistically involved with seagrass CS projects. Users who identified changes in motivations cited themes that implied a degree of environmental stewardship and project responsibility, whether by raising awareness *via* discussions or by ensuring the project's longevity through facilitating further recruitment.

Concordance was shown in deterring concepts, notably, inadequate communication and feedback, and a lack of demonstrable impact (**Figure 1**). Such deterrence likely results from perceptions that participants' time is not adequately validated for continued participation (Bruyere and Rappe, 2007) and may lead to feelings of underappreciation within users (Geoghegan et al., 2016). Project-specific barriers also arose *via* differing project approaches. Lessened influence of personal circumstance in SeagrassSpotter was likely due to reduced temporal investment, whilst prominent deterrence *via* a lack of sufficient formal training and available funds in Seagrass-Watch reflected greater task complexity, logistical, and financial investments associated with taking part (Franzoni and Sauermann, 2014). A lack of awareness of the existence of seagrass CS projects was also a significant barrier to participation (**Table 7**). Minimal public awareness of seagrass ecosystems is a known threat to their conservation and management (van Keulen et al., 2018) and results here suggest that little progress has been made to alleviate this thus far.

Perceived Knowledge of Seagrass Ecosystems

Users of both projects reported high knowledge scores. This is unsurprising given that researchers are likely to perceive increased levels of academic knowledge (Raymond et al., 2010). Variation in scores with the nature of interaction with seagrass ecosystems (**Figure 2**) is also unsurprising as traditional citizen scientists, those with minimal academic background in the subject, may have less academic knowledge of seagrass ecosystems compared to a researcher in that field. Citizen scientists may, however, hold considerable traditional ecological knowledge if they exist in close association with the oceans e.g., fishers (Drew, 2005) but may report modest scores due to the complexities of assessing knowledge (Raymond et al., 2010). Limited knowledge development reported by SeagrassSpotter users (**Table 9**) is likely influenced by researcher dominated demographics and an associated saturation of seagrass specific knowledge in this user group. Similarly, greater reported knowledge development in Seagrass-Watch may have been due to a higher proportion of citizen scientists, and thus greater potential for the attainment of novel information.

Mobile Technologies

SeagrassSpotter users demonstrated substantial support for the use of mobile phones as CS tools (**Table 8**), citing benefits that is concordant with the wider literature (Brammer et al., 2016). Despite respondent's positivity towards mobile devices, barriers to utilisation remained. Overly complex designs and requiring

TABLE 8 | Perceptions of mobile phones as data collection tools by current SeagrassSpotter users.

Do you think mobile phones are an effective data collection tool for citizen science?		**Do you think mobile phones will create further barriers to participation?**	
Yes	No		Yes No
26 (86.7)	4 (13.3)		9 (30) 21 (70)
Reason for choice	**Code**	**Frequency and valid percent**	**Example comment**
Deterring concept†	Overly complex design	6 (20)	*"if it was overly complicated or not very user-friendly"*
	Lack of interest	4 (13.3)	*"... someone not interested in seagrass"*
	Poor mobile/Wi-Fi reception	3 (10)	*"If the app does not work in low quality network, or if it requires an internet connection at all times..."*
	Nervous about wrong species ID	3 (10)	*"Confidence in identification of seagrass"*
	Perceived lack of impact	3 (10)	*"If SeagrassSpotter users didn't see their entries/data being used towards some greater purpose"*
	Challenging environment	2 (6.7)	*"...mud, unknown terrain, dangerous unseen objects. Discomfort [being] dirty"*
	Data security	2 (6.7)	*"If user data is compromised or used inappropriately"*
	Other: language, access to device, environmental impact of survey, unnecessary use	7 (23.3)	
Effective tool	Ease of access	12 (52.2)	*"...people use their mobile phones more and more and carry them with them on a frequent basis it makes the uploading of sightings easier..."*
	Technological benefits	4 (17.4)	*"Mobile phones often used to photograph and record... torch can sometimes be handy"*
	Wide data spread	3 (13)	*"Wide reach and return of greater data spread"*
Not an effective tool	Various aspects affect use	3 (13)	*"[participation] depends on volunteers, climate, geographic situation"*
	Other: general comment	1 (4.4)	*"I think phone apps are useful tools. However, I think many others can be useful to"*
Perceived barriers	No barriers	11 (55)	*"I think phones are the future. They are very user friendly"*
	Limits use to people with access	3 (15)	*"...could exclude some people in developing nations or poorer areas where smartphone use is not widespread"*
	Limits use to those comfortable	3 (15)	*"[The] project is limited to responses from people that have access to mobile phone and would feel confident using the application"*
	Reception/Wi-Fi coverage	2 (10)	*"...apps that don't require internet to run are the most accessible for those working in remote locations"*
	Other: respondent unsure	1 (5)	

†*Current Seagrass-Watch users were not asked specifically what would deter them from further participation.*

reception/Wi-Fi were cited both here (**Table 8**) and in previous assessments [e.g., Newman et al. (2011)], even when the project allowed for data submission at a later date e.g., SeagrassSpotter. Access to mobile devices and level of user comfort were also cited as barriers here (**Table 8**), however, a lack of influence of age and country of residence on perceptions suggested that these concepts may not influence participation in SeagrassSpotter. Further, "inadequate funds" was a minor deterrence in SeagrassSpotter users (**Figure 1**) suggesting access to seagrass sites (and associated travel costs) and/or mobile devices were not major barriers to participation.

Concerns over data security and correct identification of species were also raised by respondents (**Table 8**). Data handling and security present future challenges for mobile CS projects dealing with "Big Data" and should be considered a priority for future development (August et al., 2015). Despite data validation techniques being utilised in both SeagrassSpotter and Seagrass-Watch, users were still concerned about submitting erroneous reports (**Table 8**). We suggest that these features are more widely advertised to users to prevent the development of an avoidable barrier to participation (Martin V. Y. et al., 2016).

Participant Classification and Implications for the Future

Following the categorisations of Danielsen et al. (2014), the results of our questionnaire indicate that seagrass CS projects examined currently lie primarily in type E (monitoring and executed by scientists) with minor involvement of citizen scientists. The researcher heavy demographic shown here can likely be considered a result of both a lack of awareness of seagrass ecosystems and their associated CS projects within the general

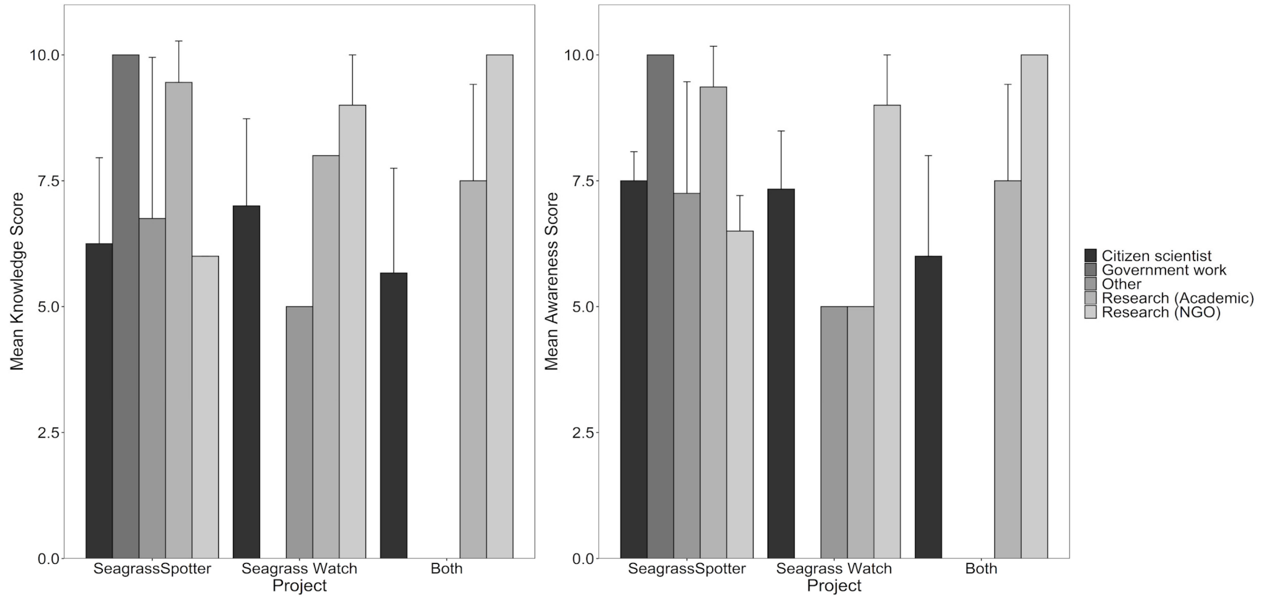

FIGURE 2 | Mean scores and standard deviation of perceived knowledge of seagrass ecosystems **(left)** and their threats **(right)** between current participants of SeagrassSpotter, Seagrass-Watch or both projects. Sample sizes by nature of interaction with seagrasses (in order of legend): SeagrassSpotter n = 4,1,4,11,2; Seagrass-Watch n = 3,0,1,1,3; Both n = 3,0,0,4,1.

public and a lack of engagement with true citizen scientists and their communities.

It is evident that seagrass CS projects need to diversify their user bases if these projects are to be viable as long term monitoring schemes. Exclusivity in projects demonstrated here also prevents these organisations from building the participant networks required to collect marine Big Data. Specifically, seagrass CS projects are suffering from reduced potential to build a diverse user base that is logistically capable of collecting data on the spatio-temporal scales needed to monitor or manage marine environmental change. For seagrass CS projects to become capable of building large, diverse user bases there is a need for better community integration. Collaborative research projects between scientists and local communities that aim to answer mutually important questions (e.g., bottom-up project creation) are far more likely to succeed due to better alignment of the interests of scientists with those of stakeholders and/or community groups (Bradshaw, 2003; Conrad and Daoust, 2008). Alignment of these interests can lead to increased motivation for participation within the local community, which gives rise to a more inclusive, and often larger, user group (Geoghegan et al., 2016); and as a result, a greater potential for Big Data collection (**Figure 3**).

Greater inclusivity in seagrass CS projects, if facilitated, may also produce secondary benefits to the project and associated communities (**Figure 3**). By enhancing the development of social capital by integrating the project (and associated researchers) into local communities, larger communication networks can be produced (Jordan et al., 2012). These networks will likely demonstrate a shared identity (e.g., people interested in conserving the marine environment) in addition to shared values, norms, and trust between parties (Pretty and Smith, 2004) and may reduce community marginalisation by facilitating social interactions with groups who would otherwise not interact (Conrad and Hilchey, 2011). Once communication networks begin to expand, so will awareness of the seagrass CS project and seagrass ecosystems more generally, leading to increased participation, a greater potential for knowledge transfer, and reductions in scientific illiteracy. Participation in seagrass CS projects may also warrant benefits for individual participants *via* the facilitation of positive interactions with nature. These interactions can pose substantial benefits to the individual [e.g., stress reduction, restoration of attention, and improved psychological wellbeing (Keniger et al., 2013)] and when combined with community-orientated changes above may lead to heightened chances of environmentally positive actions, localised environmental management and stewardship, and greater willingness to bring environmental issues to the knowledge of policymakers (Haywood, 2014; Hyder et al., 2015; Hausmann et al., 2016).

Diversification of seagrass CS projects towards greater community inclusivity may not require an overhaul of existing methodologies or the creation of new projects. Instead, existing easily understandable CS projects can be used to help local communities answer ecological questions of interest (e.g., geographic arrangement of seagrass meadows and influences on fisheries catch). It is critical that if seagrass CS projects are to be integrated in this manner that research questions are identified from a bottom-up co-research approach and that both academics and community partners are treated equally. There is increasing interest in how new technologies can become integrated into CS programmes in order to

TABLE 9 | Perceived gains in knowledge of seagrass ecosystems *via* participation in seagrass citizen science.

		SeagrassSpotter	Seagrass-watch
Do you think your knowledge of seagrass ecosystems has changed whilst taking part in SeagrassSpotter or Seagrass-Watch?	Yes	16 (53.3)	15 (93.8)
	No	14 (46.7)	1 (6.3)
Reason for choice	**Code**	**Frequency and valid percent**	**Example Comment**
SeagrassSpotter Perceived change	Location-specific knowledge	4 (28.6)	*"I have learned more about the species found on my island, and their distribution"*
	Training and methods	2 (14.3)	*"Experience and training"*
	Ecology behind observed trends	1 (7.1)	*"Discussing observation and working out reasons for change"*
	Greater environmental intervention	1 (7.1)	*"Stopped local potting inside a small area"*
	Attended events	1 (7.1)	*"I have attended several workshops and gained new insight"*
No perceived change	Considerable previous knowledge	4 (28.6)	*"…when using SeagrassSpotter I was searching for seagrass as part of my own research"*
	Lack of time for participation	1 (7.1)	*"I have been too busy this year to put any time or focus into increasing my skills and knowledge"*
Seagrass-Watch Perceived change	Attended events	2 (28.6)	*"I have learned a lot of new information through Seagrass-Watch training and subsequent monitoring events"*
	Training and methodologies	2 (28.6)	*"… learned about the techniques (transects, quadrats and soil corer, epiphytes etc.,…"*
	Wider ecological knowledge	2 (28.6)	*"…finding out about blue carbon [and], the habitats of various marine life that need seagrass to survive"*
	Ecology behind observed trends	1 (14.3)	*"Over a period of years [I] have seen some interesting trends in the data"*

TABLE 10 | Perceptions of how contributing to SeagrassSpotter helps to conserve seagrass ecosystems.

	Do you understand how your contribution to SeagrassSpotter helps conserve seagrass ecosystems?		
	Yes		No
	28 (93.3)		2 (6.7)
Perceived role of contribution	**Code**	**Frequency and valid percent**	**Example comment**
	Increasing data coverage	15 (68.2)	*"…bring more knowledge of the occurrence of different seagrass species from certain areas and so promote the importance of biodiversity in seagrass meadows"*
	Acts as groundwork	4 (18.2)	*"It may help with basic groundwork…"*
	Increasing awareness	3 (13.6)	*"Both increasing awareness and increasing coverage [of] data"*

maximise their effectiveness and expand the use of the results that are collected (McClure et al., 2020). Artificial intelligence is a particular avenue of expanding interest in CS and numerous speculative potential benefits proposed (McClure et al., 2020). Given the clear gaps in the reach of these seagrass CS programmes to wider society and particular marginalised social groups, AI could be used to align the marketing of such programmes to different groups using social media.

Further, while many CS projects rely upon the goodwill of genuinely interested members of the public, finding ways of increasing this pool of participants is necessary to increase the impact of CS. An approach to diversify participation in seagrass CS would be for conservationists and scientists to build

TABLE 11 | Perceived threats to seagrass ecosystems by current users of seagrass citizen science projects.

Perceived threat	Frequency and valid percent
Physical damage	12 (14)
Coastal development	12 (14)
Water quality	10 (11.6)
Climate change	9 (10.5)
Pollution	8 (9.3)
Runoff specifically	7 (8.14)
Fisheries	6 (7)
Sedimentation specifically	5 (5.8)
Human impacts generally	4 (4.7)
Tourism	2 (2.3)
Other: Trampling, invasive species, storms, increases in seed predators, mineral extraction, trampling, damage to sediments, plastics, land reclamation, and aquaculture	11 (12.7)

partnerships with public and private organisations, businesses, clubs and societies. This could include working with Scout Groups and Youth Clubs to undertake field sampling activities. These methods would guarantee high levels of group organisation and guaranteed numbers associated with such activities, as well as the ability to direct their participation more readily. Additionally, targeting groups which are already associated with the marine environment (e.g., water sports enthusiasts) may pose fruitful due to an existing social connection with the sea and a potentially enhanced drive to protect it.

Given the researcher-heavy demographic of seagrass CS users here, it is evident that a regime shift is needed to diversify the current user base of these projects to better promote community inclusivity if seagrass CS projects are to be able to collect Big Data. At present, although users report altruistic and environmentally positive motivations, limited deterrence, and positivity towards methods currently utilised (e.g., mobile phones), seagrass CS projects are not benefiting from increased inclusivity. Increased inclusivity, possibly as a result of improved outreach and engagement beyond the current demographic, is essential if we are to adequately conserve these important ecosystems into the future.

Continued effort is needed to increase public awareness of and exposure to seagrass ecosystems as a method of promoting enhanced environmental stewardship and to help combat the more general current trend of disconnection between humans and their local environment (Schuttler et al., 2018). Although this study focuses on a highly specific set of marine CS projects, findings here are applicable to other marine CS programmes where recruitment tends to lag terrestrial counterparts more broadly. Alignment between participant responses here and

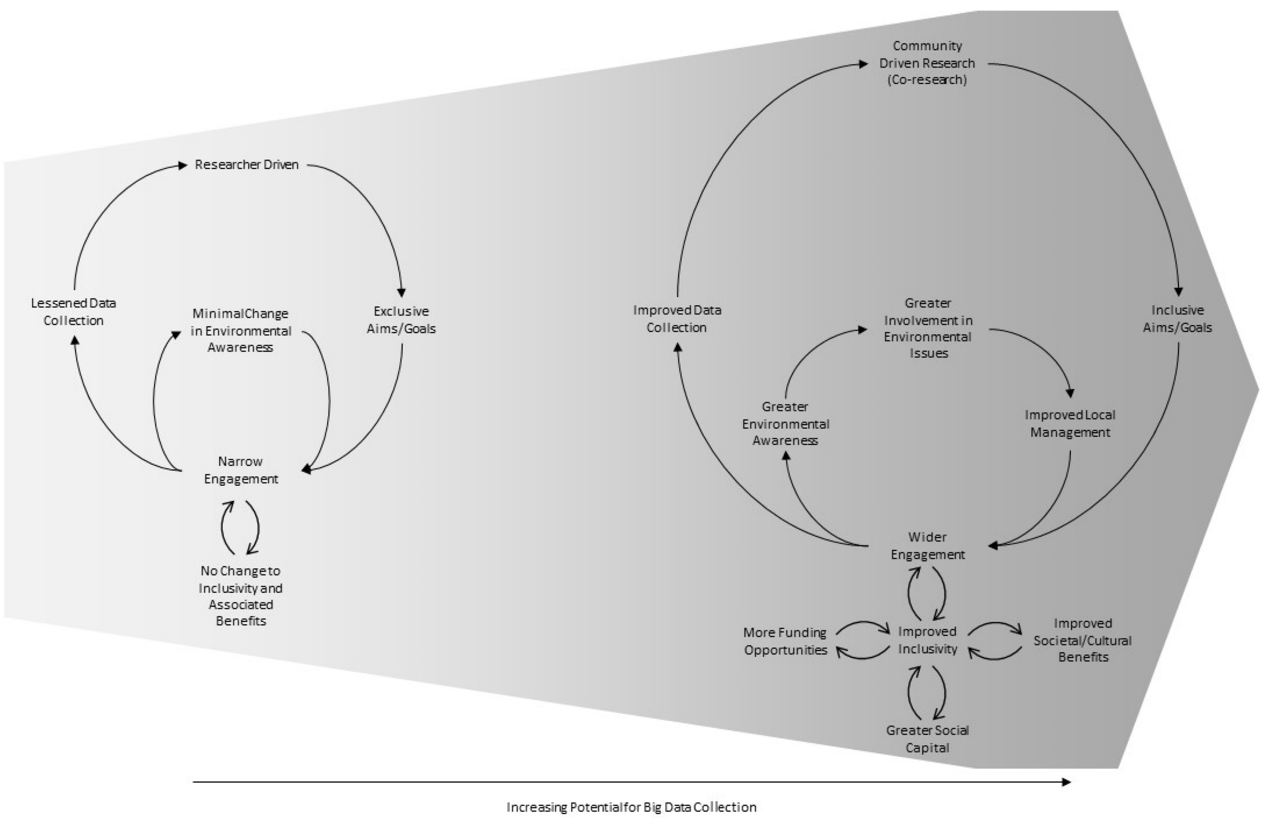

FIGURE 3 | Conceptual cycles demonstrating potential project and societal benefits associated with increased community inclusivity within citizen science projects. Darker shading indicated greater potential for Big Data collection.

existing environmental CS literature suggests that salient themes are present universally across environmental CS projects and that integrating these themes into recruitment efforts may promote better success. Given the variation in media types used by respondents here (**Table 2**), dissemination of recruitment information should be completed with a variety of media types (e.g., email, websites, in person events, flyers, etc.). Further, to encourage broader participation, recruitment efforts should stress the potential for knowledge transfer, novel social interactions, and stewardship of local environments as these concepts were primary drivers of participation in our study and in the wider literature. By targeting these drivers during recruitment, the creation of a larger and more motivated user base may be tangible.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of York Environment Department Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

OD and IS contributed *via* questionnaire creation, dissemination, and data analysis. LC-U supervised all aspects and helped conceive the initial idea. RU, BJ, and LM helped to conceive the initial idea and helped seat the manuscript in a broader context. All authors contributed to discussions and aided in the final manuscript preparation.

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ORIGINAL RESEARCH
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Transnational Municipal Networks as a Mechanism for Marine Governance Toward Climate Change Adaptation and Mitigation: Between Potential and Practice

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Many municipalities undertake actions individually and/or collectively, in cooperation with central administrations, regional authorities, the private sector, and other municipalities (both nationally and internationally). This paper aims to examine how they use transnational municipal networks (TMNs) as a tool for cooperation that supports marine governance in the context of climate change adaptation and mitigation. The analysis is carried out at two dimensions: spatial range (global or regional) and spatial identity (coastal or inland). Three case studies of TMNs are examined in detail: the C40 Cities Climate Leadership Group (C40); Connecting Delta Cities (CDC) and the Union of Baltic Cities (UBC). As research has shown, due to their organizational and normative limitations and a lack of maturity in ocean literacy, TMNs are not able to fully engage in all the activities related to climate change adaptation and mitigation as suggested by the UNEP. The TMNs implement both mitigation and adaptation measures, although 'soft' mitigation actions seem to be the most common. While the scale and innovativeness of a networks' operation are determined by their specificity resulting from their spatial identity, the effectiveness of jointly developed strategies and actions depend heavily on the allocation of human resources and the level of commitment of the involved cities toward becoming leaders.

Keywords: climate change, adaptation, mitigation, networking, transnational municipal networks (TMNs), coastal cities

INTRODUCTION

Climate change has severe consequences worldwide. These consequences – such as a temperature rise or violent weather phenomena – are deepening. This means that they occur more frequently, with greater intensity and on an increasing scale (UNEP, 2019a; NASA, 2020; Pakszys et al., 2020). Cities are particularly sensitive areas, especially coastal ones. In cities with a high population density, the adverse effects of climate change are even more compounded (Heikkinen et al., 2020). The intensification of urban heat islands, a rise in sea-levels, heavy rainfalls causing flooding, strong winds, associated changes in storm patterns, and erosion- are a threat to coastal ecosystems as well as to local economies and human life (Hallegatte et al., 2013; Wong et al., 2014).

Actions undertaken by city authorities should be carried out in two ways: as an adaptation to climate change, and in the form of mitigation (Shi et al., 2016). Implementation of mitigation and adaptation actions is a process that requires the involvement of many actors and institutions on a local, regional, national, and international level (Dupuis and Biesbroek, 2013; Busch et al., 2018; Donatti et al., 2020; Kotynska-Zielinska et al., 2020). Cities undertake actions individually and/or collectively, in cooperation with central administrations, regional authorities, the private sector, and other cities [both nationally and internationally] (Woodruff and Stults, 2016; Heikkinen et al., 2020).

From our point of view, it is particularly interesting to explore international city-networking which is understood here to be a form of bottom-up governance. This paper, therefore, aims to examine how cities (primarily coastal) use networks as a tool of cooperation that supports marine governance in the context of climate change adaptation and mitigation. The analysis is carried out at two dimensions: the spatial range (global or regional) and spatial identity (coastal or inland). Three case studies are examined in detail: C40 Cities Climate Leadership Group (C40), Connecting Delta Cities (CDC), and the Union of Baltic Cities (UBC). The goals of this analysis are to empirically examine (i) what kind of actions prevail in climate-change related cooperation, and (ii) how effective networking is in addressing the challenges of global warming. In other words, within the scope of the first goal we investigate whether networks of cities focus on adaptation or mitigation, and how visible (or how important) the marine environment appears to be in terms of their actions. Within the scope of the second goal, we explore if networks of cities have progressed from soft cooperation instruments (mainly focused on the exchange of knowledge and best practices; e.g., Mansard et al., 2017; Heikkinen et al., 2020) toward more innovative and concrete actions, and whether they have introduced any monitoring activities that would allow to assess the uptake and effectiveness of jointly developed strategies and actions.

CLIMATE CHANGE – SCOPE OF CHANGE AND CONSEQUENCES (PARTICULARLY FOR COASTAL CITIES)

The land surface air temperature has increased almost twice as much as the global average temperature in less than 250 years. The International Panel on Climate Change (IPCC) reported that economic losses related to weather and climate-related problems in 2017 in conjunction with extreme temperatures, heatwaves and a vast number of wildfires in 2018 were at a record high (Wong et al., 2014; UNEP, 2019a). Climate change severely impacts marine and terrestrial ecosystems. It impacts every aspect of our lives by influencing both social and ecological systems and their interactions. It is obvious that climate change also poses a serious threat to coastal communities, and this is particularly associated with rising sea levels (Hay et al., 2015). Clearly humanity needs to understand that adaptation to climate change is not an option anymore, it is a real need (IPCC, 2014, 2019; Donatti et al., 2020).

The observed climate pattern changes, including both natural and anthropogenic forcing factors are very clearly manifested as a rise in sea level, which has become one of the key indicators of global climate variability (UNEP, 2019a). The sea level rise is a result of water input from melting glaciers and ice sheets as well as an increase in ocean water volume due to its warming.

By 2100, the sea level rise may reach or, in extreme cases, even exceed 2 m if we do not reduce and/or increase atmospheric pollution (greenhouse gases) emissions (Kopp et al., 2017; Kulp and Strauss, 2019).

Humans have ever since settled by the sea. Such a choice relates to a number of factors, such as the prevalence of natural resources, good transportation means, and thereby the facilitation of trade and defense. Maritime transport provides the main means of global import and export of goods. In the European Union, it has been estimated that around 40% of the EU's external freight trade relies on maritime transport (Collet and Engelbert, 2013).

Today it is estimated that some two-thirds of the world's population inhabits coastal areas (defined as a region within 60 km of the coast), and therefore these areas exhibit much higher population densities than other regions of the world (Un Atlas of the Oceans, 2020). As a result, the UN Atlas of the Oceans also reports that close to 50% of the world's large cities (with populations exceeding one million) are located in these areas (Un Atlas of the Oceans, 2020).

A rise in sea level endangers coastal infrastructures around the world, including ports, shipyards and recreational facilities, which are crucial for local job markets and industries. Understanding how a sea level rise may impact coastal areas and their populations is critical for coastal planning and the assessment of potential benefits and costs of climate mitigation, as well as the costs of disasters due to a lack of proper action (Nauels et al., 2017; Kulp and Strauss, 2019).

Coastal urban areas (cities) are critical regions, which will be most affected by a rise in the sea levels driven by climate change. Very often, coastal urban areas are comprised of areas of reclaimed land, which is protected from change (mostly erosion) by means of human made constructions, such as seawalls and rock based structures. Recent estimates show that many coastal regions (mostly urban areas) have over 50 percent of their coastlines strengthened by engineering structures (Chee et al., 2017). The existing protective structures cannot be assumed as adequate to protect against projected future sea levels and storms and with predicted changes in world coastlines, these structures will have to be adapted and/or strengthened in order to be still functional in protecting the land from the sea (Lincke and Hinkel, 2018).

Hallegatte et al. (2013) reported that in the case of 136 of the biggest coastal cities flood related losses would increase from an average of US$6 billion per year in 2005 to US$1 trillion by 2050. On the other hand, well prepared coastal urban areas, which are usually economically strong and enjoy steady economic growth may become centers for climate change mitigation and adaptation activities and hence be the leaders in such type of actions.

ADAPTATION AND MITIGATION STRATEGIES AND PRACTICES

The IPCC defines climate related adaptation as: "the process of adjustment to actual or expected climate and its effects," which can be translated to those actions that minimize the adverse effects of climate change. Mitigation of climate change, on the other hand, according to the IPCC relates to "human intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC, 2012, p. 556, 561).

In its 5th report, the IPCC compared both approaches and stated that: "many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself" (IPCC, 2014, p. 26).

However, it is obvious that these two strategies, even though both necessary, are quite different, since they produce different outcomes. Adaptation is more related to smaller scale actions (on local and regional levels), while mitigation is a global issue and can be mostly tackled on a much greater scale than adaptation activities.

By their nature, we know that mitigation actions will take several decades to prove to be successful, and so, it is obvious that humans need to keep adapting to the changes which we all experience nowadays and will experience in the future.

There exist a number of approaches to tackle climate change adaptation and mitigation challenges. In order to measure their potential efficiency, certain universal indicators that have the ability to measure the scale of success need to be applied. Most of the indicators are either initiated by the United Nations and their agendas [e.g., Global Adaptation Network (GAN) and Global Centre of Excellence on Climate Adaptation (GCECA)] or are interconnected with the UN [e.g., World Adaption Science Programme (WASP), which was one of the four components that formed the World Climate Programme (WCP) based on the WMO Congress XVI Resolution 18 and has five partners, including the Meteorological Organization (WMO), the Intergovernmental Panel on Climate Change (IPCC), the Green Climate Fund (GCF). The fifth partner, the United Nations Framework Convention on Climate Change (UNFCCC) is hosted by the UN Environment Programme (UNEP)].

The major goal of the 2015 UNFCCC (United Nations Framework Convention on Climate Change) Paris Agreement is to enforce all actions in order to keep the global temperature rise up to 2°C above pre-industrial levels and to strengthen efforts to keep the temperature rise below 1.5°C (IPCC, 2018). However, in order to be realistic, meeting any of these targets will still not resolve all climate change related problems and climate change adaptation measures will still be required. Therefore, the United Nations Environmental Programme is involved in climate change adaptation actions, which are ecosystem-based (UNEP, 2012, 2015; Donatti et al., 2020).

The United Nations has agreed on a total of 93 environment-related Sustainable Development Goals (SDGs) indicators, and the United Nations Environment Programme is responsible for 26 of these indicators. Therefore, the United Nations Environment Programme continues its activities that are focused on developing and refining methodologies to measure SDGs targets, with a focus on climate change adaptation and mitigation aspects.

The four basic UN promoted areas of climate change adaptation activities includes: (1) projects that utilize biodiversity and ecosystem services as part of a holistic adaptation strategy (Ecosystem-based adaptation – EbA); (2) spreading vital adaptation knowledge through well-connected global networks; (3) providing an interface between the adaptation research community and decision-makers (such as the World Adaptation Science Programme – WASP) and (4) supporting countries to advance their National Adaptation Plan (NAPs) processes (UNEP, 2020).

In case of mitigation, eight indicators have been defined by the United Nations Environment Programme Report of 2018, which focus on activities related to climate change and include: (1) minimizing the scale and impact of climate change, (2) minimizing environmental threats, (3) supporting human well-being through healthy ecosystems, (4) strengthening governance, (5) ensuring sound management of chemicals and waste, (6) accelerating the transition to sustainable societies, (7) promoting evidence-based decision-making, and (8) providing knowledge to policymakers (UNEP, 2019b).

In the remainder of the paper, the authors decided to use the mentioned eight climate mitigation indicators and four climate adaptation indicators, as those are officially accepted by the United Nations and thus should provide the most universal tool.

NETWORKING AS A TOOL IN THE MARINE GOVERNANCE

Responding to climate change is associated with numerous challenges (Hajer et al., 2015; Xue et al., 2018; Grainger-Brown and Malekpour, 2019; Salvia et al., 2019), including issues related to different aspects, sectors and levels of governance (Visseren-Hamakers, 2015; Biermann et al., 2017; Kanie and Biermann, 2017; Florini and Pauli, 2018; Glass and Newig, 2019). This also applies to the implementation of numerous SDGs, including Goal 13 and 14 and ocean governance, which seem to require a profound transformation based on a more holistic approach (Vierros, 2017). While the effectiveness of sustainable ocean governance depends on different aspects (Glass and Newig, 2019), its organizational forms are essential (Berkowitz et al., 2020), particularly in case of transition governance (Monkelbaan, 2019). As van Leeuwen and van Tatenhove argue, "the dynamics of marine policy making and the power games between different maritime activities and stakeholders [. . .] are increasingly embedded in a multi-level setting and in a rapidly changing institutional context" which is characterized by a "shift from state-led to new, network-like governance arrangements" (van Leeuwen and van Tatenhove, 2010, p. 590). This observation suggests that transnational networking (Risse-Kappen, 2009) of municipal actors can play an important role in the ocean governance for sustainable development, as well as for climate change adaptation and mitigation (Betsill and Bukeley, 2004; Bäckstrand, 2008; Andonova et al., 2009; Florini and Pauli, 2018).

According to a basic understanding, the network consists of nodes and links which display a pattern of connectivity (Taylor and Derudder, 2016). Despite the fact that the term 'network' is widely used in different contexts in the literature and represents many scientific disciplines such as transportation, telecommunication, geography, management, sociology and politics (Camagni and Salone, 1993; Ward and Williams, 1997; Sassen, 2002; Taylor and Derudder, 2016), in the social sciences domain a network as a research category is basically applied as an analytical tool or as a form of governance (Forsman and Solitander, 2003, p. 4). In the latter, three approaches to the study of networks can be distinguished: (1) networks as a mode of social coordination, (2) networks as systems of sectoral governance, and (3) networks as interorganizational relations (Halkier and Damborg, 1997, pp. 6–7). According to Torfing, "Transnational governance networks can be understood as a horizontal articulation of interdependent, but operationally autonomous, actors from the public and/or private sector who: (1) interact through ongoing negotiations that take place within a regulative, normative, cognitive, and imaginary framework; (2) facilitate self-regulation; and (3) contribute to the production of public regulations" (Torfing, 2012). Based on past research one can indicate that networks are webs of relatively stable and ongoing relationships between interdependent social actors which acquire or mobilize dispersed resources so that collective (or parallel) actions can be orchestrated toward a solution within the scope of tackling a common policy problem (Kenis and Schneider, 1991, p. 36; Conti, 1993, p. 126; Marsden, 2000, pp. 2727–2728; Forsman and Solitander, 2003, p. 5; Mingus, 2007).

The driving force in the establishment of governance networks is the social and political actors' recognition of their mutual dependence (Torfing, 2012) as well as micro-level incentives and diffusion processes that create and spread normative impacts (Andonova et al., 2017, p. 253). While transnational governance networks "provide a functional response to the growing differentiation, complexity, and multilayered character of modern societies" (Torfing, 2012, p. 106), they are established via flexible co-operation processes such as agreements of understanding, rather than being formal results of intergovernmental agreements (Cannarella and Piccioni, 2008; Andonova et al., 2009). It is commonly emphasized that the standing of such networks is associated with their "ability to provide information, create knowledge, and to forge norms about the nature and terms of particular issues" (Betsill and Bukeley, 2004, p. 2). One of the areas of territorial network cooperation is urban development. In this context urban networking is understood as both a way of arranging strategic development within the urban region and as a way of organizing co-operation between urban regions (Varitiainen, 2000). While urban networking relates to a specific subset of cooperation, the term municipal networking relates to a form of co-operation between cities, which is examined in two different sets of academic literature: in urban studies (which includes subjects such as political geography and urban sociology) and in political studies (political science, political sociology, and international relations).

As Salomon argues, municipal networks are voluntary cooperation schemes constituted by local governments with varying degrees of institutionalization (Salomon, 2009), where "cooperation tends to get a synergetic effect in which the achievable output (. . .) is higher than the one that single cities could gain through the exploitation of their single resources" (Rossignolo, 2009, p. 13). There are three main different types of networks. Firstly, there are networks of metropolises – world cities – which perform the whole range of city functions and compete and co-operate amongst themselves at the same time (Sassen, 2001). Secondly, there are networks of specialized national cities, which co-operate with each other as and when desirable (Conti and Spriano, 1989), and lastly there are networks of specialized regional cities, which also co-operate as and when advantageous. The first type of network is essentially one which is based on synergy, whilst the others are either specialized or complementary networks (Ercole et al., 1997, p. 221).

Since the advent of Agenda 21 cities have been engaged in the development of environmental sustainability and the amount of transnational municipal networks (TMNs) that address related challenges have grown (Bouteligier, 2014, p. 57). We here define such TMNs related to climate change to be organizations that aim to support cooperation between cities to improve their climate change mitigation and adaptation work. TMNs can require cities to adopt certain quantitative or qualitative climate goals. They organize events, produce information (e.g., reports on their members' climate actions), offer tools and/or resources and represent cities internationally. TMNs originally concentrated on mitigation, but adaptation has increasingly become part of their agenda (Heikkinen et al., 2020). Today, there exists a large variety in TMNs for the purpose of global environmental governance. Some are large (e.g., the International Council for Local Environmental Initiatives – Local Governments for Sustainability, or ICLEI), whereas others are smaller (e.g., the Mega-Cities Project), they can have a broad scope (Metropolis) or focus on a specific issue (Energie-cités) and they can appeal to smaller (the Sustainable Cities and Towns Campaign) or larger (the C40 Cities Climate Leadership group) cities (Bouteligier, 2014, p. 57). The different types of TMNs can be distinguished according to different criteria, such as: (1) the degree of institutionalization: strong or weak; formal or informal; (2) spatial range (global or regional); (3) spatial identity (costal or inland); (4) the scope of activities and areas of actions – engaged in many issues and tasks or concerned with a specific policy area or even a single task (Betsill and Bukeley, 2004; Bäckstrand, 2008). One might distinguish two other types of networks – the so-called synergy network, made up of similar cities, and the complementary network, made up of specialized but complementary cities (Ercole et al., 1997, p. 221). An important distinction is also between dispersed networks and adjacent networks – the former encompasses cities located in distant localities, the latter are made up of neighboring cities (Dumała, 2012).

Transnational governance arrangements provide many governance functions – such as rule-setting, dispute resolution, and public good provision – which are traditionally associated with national governments and intergovernmental organizations (Andonova et al., 2017, p. 256). TMNs allow for the sharing of knowledge and best practices, the coordination of action, or joint problem-solving (Torfing, 2012); moreover, they facilitate better communication and cooperation as well as innovative policy diffusion (Feldman, 2012). They also provide access to resources, markets and capabilities allowing for the combination of different pieces of knowledge (Cassi et al., 2008). Bringing together municipal governments to cooperate on tackling common environmental problems, TMNs serve as international communication and representation platforms providing cities with the opportunity to voice their concerns (Bouteligier, 2013a). Cities from different regions and countries tend to share their experiences and their cultures within the networks in order to develop common spatial or social strategies and further cooperation (Baycan-Levent et al., 2010).

Research on the activities of TMNs in the field of adaptation and mitigation of climate change is relatively new in the literature. Scholars are interested in e.g., the role of TMNs in shaping the trend of the emerging urban climate governance (Bulkeley et al., 2003; Toly, 2008; Kern and Bulkeley, 2009; Juhola and Westerhoff, 2011; Lee, 2013), their effects, including their capacity to generate novelties (Papin, 2019, 2020), the role of networks in urban 'experimentation' (Smeds and Acuto, 2018), and the actual impact of network participation, especially in the context of adaptation (Heikkinen et al., 2020).

ANALYTICAL FRAMEWORK

Materials and Methods

In order to investigate whether city networking is a useful tool to address climate change-related issues, we have analyzed the documents and activities of three city networks, i.e., (i) the C40 Cities Climate Leadership Group (C40), (ii) CDC, and (iii) the Union of the Baltic Cities (UBC). We have chosen these three networks in order to illustrate the various types of cooperation described in the literature (**Table 1**). By doing so, we attempt to explore whether network characteristics (e.g., spatial range or the degree of institutionalization) influence the forms in which adaptation and mitigation are perceived and addressed.

We analyzed materials and documents available on the networks' webpages; the analysis was performed between March and July 2020. Due to the large amount of available materials, we have adopted two criteria to guide our analysis. Firstly, we have only considered the activities of a given network as a whole, i.e., even if webpages provided additional materials about climate-related activities and achievements of individual members, such information has been excluded from the analysis. This approach allowed us to focus on 'networking,' i.e., joint activities and the possible added value of operating within a community of interests. Secondly, we predominantly focused on (i) high-level and strategic documents, and (ii) the information included in the major segments of the networks' webpages. In other words, we have neither analyzed in detail the content of all reports and publications prepared by the network, nor the content of other resources that were accessible through the provided links. Our analysis was complemented by using a search engine, i.e., in each case, we used key phrases related to each mitigation and adaptation indicator (**Tables 2**, **3**) in order to identify content that could have been omitted in the previous step.

We used the content analysis (interpretation of text; Krippendorf, 2004). The relevant content was identified and synthesized according to two sets of pre-defined criteria. Firstly, we explored how network activities fit into (or are relevant to) UNEP mitigation and adaptation indicators (**Tables 2**, **3**). We approached the criteria broadly, i.e., we assumed that 'an action' or 'a statement' addresses the indicator if its results could contribute to the ambitions described by UNEP. Therefore, we did not expect that a certain word or phrase (e.g., 'productivity' in case of indicator three) necessarily needs to appear in the text to have the text classified as relevant to a given indicator. Secondly, each of the network's activities[1] was assigned to one instrument of networking (**Table 4**). This allowed us to identify what types of cooperation and what instruments are most commonly employed in climate-related networking at the city level. The list of instruments followed the classification put forward by Dumała (2012), which we arranged according to three areas of activities covering the main functions that are performed by transnational networks (Andonova et al., 2009; Strange, 2012; Niederhafner, 2013). In her work, Dumała (2012) presents a comprehensive overview of the various types of cooperation instruments that were applied by dispersed territorial networks in Europe. As the networks we analyzed include cities from all over the world, and not only within Europe, we did not take into account those instruments that are unique to the European area, such as cooperation with the Committee of the Regions or an office in Brussels.

Networks – Case Studies

The C40 Cities Climate Leadership Group (C40)

The C40 Cities Climate Leadership Group was established (as C20) in October 2005 in London during the World Cities Leadership and Climate Summit, which was attended by 18 major cities form Europe, America and Asia (Barcelona, Beijing, Berlin, Brussels, Chicago, London, Madrid, Mexico City, New Delhi, New York, Paris, Philadelphia, Rome, San Francisco, São Paulo, Shanghai, Stockholm, Toronto, and Zurich). By 2006, the number of cities had grown to 40, and therefore the name was changed into C40. In April 2011 there was a formal merger between C40 and the Clinton's Climate Initiative Cities Programme (C40, 2016a, p. 8).

C40 is a formal network with the status of a non-profit organization registered in the United States and has registered offices in New York (United States), London (United Kingdom) and Pretoria (South Africa), and a representative office in Beijing (China).

C40 is global in spatial range – it connects 94 of the world's greatest cities (Africa 12, Europe 20, Latin America 12, North America 17, Asia and Oceania 33), representing over 700 million

[1]'A document' or 'a report' was considered as an activity for the purpose of this analytical step.

TABLE 1 | Overview of the analyzed networks.

Categorization criteria	C40 Cities Climate Leadership Group (C40)	Connecting Delta Cities (CDC)	Union of Baltic Cities (UBC)
Degree of institutionalization	Formal	Informal	Formal
Spatial range	Global	Global	Regional
Spatial identity	Coastal and inland	Mainly costal	Mainly coastal
Scope of activities	Specialized (focus on climate change)	Specialized (focus on climate change)	Multi-sectoral

people and 25% of the global GDP (C40, 2020a). There are three types of membership categories in C40: Megacities, Innovator Cities and Observer Cities (C40, 2012). The members include both coastal and inland cities.

The C40 organizational structure includes: a Steering Committee – consisting of the mayors of C40 cities, and provides strategic direction and governance for C40. Members are elected to represent cities from within their respective geographic regions (7: Africa; Central East Asia; East, South-East Asia & Oceania; Europe; Latin America; North America; South and West Asia), in addition to a representative from the ranks of C40's Innovator City members. The C40 Board of Directors oversees the management and day-to-day activities of the organization. The Chair is the elected leader of the organization. The Chairmanship is a rotating position (C40, 2020b). C40 summits are held every 2 years. This event has so far been held in London (2005), New York City (2007), Seoul (2009), São Paulo (2011), Johannesburg (2014), Mexico City (2016), and Copenhagen (2019).

The network activities are conducted through 16 inner networks in five policy areas closely related to climate change in which city governments are most likely to be equipped with the necessary legal powers to take action: Air Quality; Food, Waste and Water; Energy and Buildings; Transportation and Urban Planning; Adaptation, Implementation (C40, 2020c). The C40 is therefore a specialized, monothematic network. The specific aim of the C40 is the creation of a Global Green New Deal – a series of essential steps to "cut emissions, invest in clean energy, protect natural resources on a global scale, and ensure a just transition for all, and particularly the most disadvantaged" (C40, 2019, p. 2).

C40 has been present on all major social media platforms since 2011 and works with many other public and private partners.

TABLE 2 | UNEP climate mitigation indicators.

Indicator and focus area
(1) Minimizing the scale and impact of climate change
– Climate resilience
– Low-emission growth
– REDD + (reduce emissions from deforestation and forest degradation)
(2) Minimizing environmental threats
– Risk reduction
– Response and recovery
(3) Supporting human well-being through healthy ecosystems
– Creating an enabling environment
– The productivity of terrestrial and aquatic ecosystems
– The productivity of marine ecosystems
(4) Strengthening governance in an interconnected world
– Coherence and synergies
– Stronger laws and institutions
– Mainstreaming of environment into development planning and decision-making
(5) Ensuring sound management of chemicals and waste
– Creating an enabling environment
– Chemicals
– Waste
(6) Accelerating the transition to sustainable societies
– An enabling policy environment
– Sustainability in businesses
– Sustainable lifestyles and consumption
(7) Promoting evidence-based decision-making
– Assessments
– Early warning
– Information management
(8) Providing knowledge to policymakers

Source: UNEP (2019b).

Connecting Delta Cities

The Connecting Delta Cities is a sub network within the framework of the C40 and it brings together delta and coastal cities that are active in the field of climate change related spatial development, water management and adaptation (Molenaar et al., 2013). It was founded following a workshop on climate change adaptation in C40 cities that was organized in Tokyo in 2008 (Molenaar et al., 2013).

The CDC connects 13 cities (Rotterdam, Tokyo, Jakarta, Hong Kong, New York, New Orleans, London, Ho Chi Minh City, Melbourne, Copenhagen, Venice, Singapore, and Washington DC) and it is led by Rotterdam (C40, 2020d).

The CDC Network was established to deliver concrete climate change adaptation actions by supporting cities in developing and

TABLE 3 | UNEP climate adaptation indicators.

Indicator
Ecosystem-based adaptation (EbA): Implementing projects that utilize biodiversity and ecosystem services as part of a holistic adaptation strategy
Knowledge, analysis and networking: Spreading vital adaptation knowledge through well-connected global networks
World Adaptation Science Programme (WASP): Providing an interface between the adaptation research community and decision-makers
National Adaptation Plans (NAPs): Supporting countries to advance their National Adaptation Plan process

Source: UNEP (2020).

TABLE 4 | List of cooperation instruments.

Type of activity	Instruments
Collaboration (external)	Cooperation with other urban networks
	Lobbying
	Scientific and academic cooperation
Cooperation between cities-members	Exchange of good practices
	Statements/declarations
	Study visits
	Thematic conferences, workshops, seminars, webinars
	Working groups/subnetworks
Education and outreach	Communication tools (website, newsletter, social media)
	Database
	Educational materials
	Publications
	Summer schools

Source: Adapted from Dumała (2012).

implementing their climate change adaptation strategies. This goal has been achieved through (1) exchanging knowledge on climate adaptation, (2) sharing challenges and lessons learned, policy and infrastructure solutions, research and information, (3) discussing technical and financial partnerships with one another, and (4) facilitating the sharing of good practice and technical expertise (Molenaar et al., 2013; CDC, 2017; C40, 2020d).

While at the policy level the CDC links cities together via bi-lateral Memoranda of Understandings and Letters of Intent, the organizational dimension of cooperation is more composite. In general, the involvement of each city depends on how the individual cities have organized the development of their adaptation plans. Usually, each city has a pool of institutes and experts (policy experts, scientists, business professionals) involved in developing and implementing adaptation plans and these entities are encouraged to participate in a network to support CDC activities (mainly conferences and joint publications) by providing information on climate trends, impacts and adaptation options. In order to manage the flow of information between CDC cities, a small CDC secretariat has been installed in Rotterdam (CDC, 2017). CDC cities have prioritized focus areas which include (C40, 2020d):

- Systematic Adaptation – Moving from *ad hoc* adaptation to integrated systematic and holistic adaptation;
- Sustainable Urban Drainage – green infrastructure and surface drainage typologies and policies for delta cities;
- Monitoring and Evaluation – methods and standards for indicating the efficacy of adaptation actions;
- Cost-benefit and Co-benefit Assessment – providing economic and social justification for adaptation actions.

CDC cities are among the most advanced in terms of climate change adaptation and are prepared to open themselves up to broader cooperation with peer cities around the world by sharing good practices with them (C40, 2016b, p. 9). While since 2017 the CDC network has limited its activities, a contacted C40 officer claims that there are plans to reinvigorate the network.

In the context of the introduced classification of the TNMs, CDC is an informal network with a weak level of institutionalization, with a global spatial range. It is characterized by delta and/or costal spatial identity, and its activities are focused on selected areas related to the fields of climate change-related spatial development, water management and adaptation.

The Union of Baltic Cities (UBC)

Union of Baltic Cities is a voluntary, proactive, international network, which was founded in 1991 in Gdańsk (Poland), and comprises of cities from ten countries around the Baltic Sea Region (BSR): Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, Russia, and Sweden. UBC has the following structure (UBC, 2020a): a General Conference, an Executive Board, a Presidium, Commissions, a Secretariat and Board of Audit. The network activities are conducted through seven Commissions: Cultural Cities, Inclusive and Healthy Cities, Planning Cities, Safe Cities, Smart and Prospering Cities, Sustainable Cities, and Youthful Cities (UBC, 2020b). The UBC Commissions are established by the General Conference and they are responsible for member cities' actions in key areas of interest. The Commissions have their own budgets with various sources of income, and they are responsible for activities which involve; projects, meetings, seminars, exchange programs, events, publications, etc. (UBC, 2020a). The Commissions provide consultations, advice, and initiatives to attract financial resources for those projects that are selected at annual meetings of the Commissions and they report to the Executive Board and to the General Conference (UBC, 2020a).

The UBC's overarching aim is to mobilize and share the potential of its member cities. The specific aims of the UBC are to (UBC, 2015, p. 1):

- Promote cooperation and facilitate the exchange of experiences between cities in the BSR to advance and deliver sustainable urban solutions and promote the advancement of the quality of life, and thereby foster added value.
- Promote cities as drivers for smart, sustainable, green and resource-efficient growth.
- Advance cities as inclusive, diverse, creative, democratic and safe hubs, where active citizenship, gender equality and participatory policy making are promoted.
- Advocate in favor of common interests of cities and their citizens, act on their behalf and further the interests of the BSR.

The UBC and its Member Cities work in close cooperation with other partners and participate actively in the implementation of regional strategies, notably the European Union Strategy for the Baltic Sea Region.

The UBC pays strong attention to sustainable development and climate change issues. During the 15th UBC General Conference, which was held on 15–18 October 2019 in Kaunas, Lithuania, the Resolution on Climate Change Adaptation and

Civil Protection was accepted and will be realized in the upcoming years (UBC, 2019).

RESULTS

Relevance of UNEP Indicators

The analysis of the networks' webpages resulted in the identification of a plethora of activities and statements related to mitigation and adaptation efforts undertaken by the networks as a whole (**Tables 5**, **6**).

Out of the three analyzed networks, UBC seems to include climate change mitigation and adaptation ambitions most comprehensively in its activities. This is surprising as it is the only multi-sectoral network that does not singularly focuses on climate change. Despite being coastal in its core and hence being more vulnerable to a rise in sea level and its associated effects, the CDC shows little interests in climate change-related actions (even though it defines itself as an organization that focuses on the effects of global warming). However, this network is – in general – less active than the other two networks; this is perhaps because it has a more informal character, and is merely a part of a larger formalized organization, i.e., C40.

Nevertheless, the analyzed networks address the majority of UNEP mitigation and adaptation indicators. The issues related to climate change are present both in the forms of statements in the networks' documents, and in practical actions undertaken by the networks themselves and their member cities. The CDC is the least active network, which is demonstrated by the limited number of indicators present in this network's activities.

But what about preferences for mitigation and adaptation indicators? The answer is that our analysis does not reveal any clear patterns. The comparison is even more difficult because of the relatively great difference in terms of numbers between adaptation and mitigation indicators. It seems that the UBC is active in both areas, i.e., its actions and statements cover all adaptation activities (**Table 6**) and the majority of mitigation activities (over 90%; **Table 5**). C40 seems to be more active in the field of mitigation, while CDC seems to prefer climate adaptation. However, the last result is subject to severe limitations since this network does not seem to be truly operational.

Overall, our results suggest that the geographical coverage – or otherwise the vicinity of the location(s) – is the most important factor that shapes the preferences for adaptation or mitigations actions. Hence, the UBC seems to be the leader in the climate change related actions when compared with the other two networks. We can speculate that it is both due to the shared resource (i.e., the Baltic Sea) that connects the cities but also due to the influence of the European Union and its policies have on the network's own policies and strategies. Indeed, the UBC is quite efficient in absorbing the European funding, and this obviously requires that the organization is familiar with the European ambitions and embrace them in own (strategic) goals and activities.

It is perhaps not surprising that the most common indicators are those that pertain to knowledge. All three networks undertake actions to disseminate information and best practices on how to adapt or how to mitigate the effects of global warming. The C40 'Climate Change Adaptation Monitoring, Evaluation and Reporting (CCA MER) Framework' illustrates such efforts. This framework was developed to assist city planners and policymakers in identifying best practices and measuring progress toward climate change adaptation. Another example is the UBC initiative to create a series of webinars related to various (environmental) topics such as stormwater management or CDP reporting.

Overall, there are few differences between the two active networks. However, one difference seems to be most notable. It is a lack of focus on productivity and the state of health of various types of ecosystems (mitigation indicator no. 3; **Table 5**). Only UBC explicitly mentions the state of natural ecosystems in its 'Sustainability Action Programme 2016–2021' aiming to increase biodiversity in urban areas or the enhancement of the ecological status of the Baltic Sea. Although these goals are rather general, they are accompanied by at least some concrete actions. Perhaps the most prominent example of practical actions is the Baltic Smart Water Hub; an on-line tool that collects good practices and ready-to-implement technical solutions and tools within the scope of four thematic areas; i.e., fresh water; sea water; storm; and waste water. Among the available resources, some directly concern adaptation to climate change (e.g., Energy Performance and Carbon Emissions Assessment and Monitoring) or support the enhancement of the ecological status of natural ecosystems (e.g., the Green Area Factor). UBC is also the network that includes an ecosystem-based adaptation in its policies and – to a limited extent – in its actions, i.e., the already mentioned Green Area Factor that in its description underlined the role of green infrastructure (green surfaces) in addressing climate change. Interestingly, this approach is strongly recommended by the CDC, which underlines not only the role of green infrastructure but also blue one.

This lack of focus on ecosystems and their productivity is interesting, especially since all networks have declared efforts to promote environmental sustainability into planning and policy-making. It seems that within the scope of this indicator, cities forming the networks focus on emission neutrality, water storage or providing barriers between the sea and the urban coast while not linking any of these benefits with the health of seas and oceans (and land). Our analysis does not allow us to provide plausible justification for this situation. Nevertheless, we can speculate that it is again the vicinity of the Baltic Sea that makes UBC the front-runner in this area as well. The Baltic Sea region countries have long cooperated in the field of environmental protection (e.g., Kern, 2011) and it is likely that the network of cities from the region follows or at least embraces ambitions widely accepted at respective national levels. Cooperation with the EU and its funding does probably provide additional important trigger that brings UBC toward larger recognition of having a sound environmental status.

Analysis of Networking Tools

The available data on the three examined networks allows the identification of a set of 17 instruments used by the networks that focus on climate change. During the research

TABLE 5 | Networks and UNEP climate mitigation indicators[2].

Indicator	Focus area	C40	CDC	UBC
(1) Minimizing the scale and impact of climate change	Climate resilience	S/A	–	S/A
	Low-emission growth	S/A	–	S/A
	REDD + (reduce emissions from deforestation and forest degradation)	–	–	–
(2) Minimizing environmental threats	Risk reduction	A	S	S/A
	Response and recovery	A	–	S/A
(3) Supporting human well-being through healthy ecosystems	Creating an enabling environment	S/A	–	S/A
	The productivity of terrestrial and aquatic ecosystems	–	–	S/A
	The productivity of marine ecosystems	–	–	S/A
(4) Strengthening governance in an interconnected world	Coherence and synergies	S/A	–	S/A
	Stronger laws and institutions	S	–	–
	Mainstreaming of environment into development planning and decision-making	S/A	S/A	S/A
(5) Ensuring sound management of chemicals and waste	Creating an enabling environment	S/A	–	S/A
	Chemicals	–	–	S/A
	Waste	S/A	–	S/A
(6) Accelerating the transition to sustainable societies	An enabling policy environment	S/A	–	S/A
	Sustainability in businesses	S/A	–	S/A
	Sustainable lifestyles and consumption	S/A	–	S/A
(7) Promoting evidence-based decision-making	Assessments	A	–	S/A
	Early warning	A	–	S/A
	Information management	S/A	–	S/A
(8) Providing knowledge to policymakers		A	S/A	S/A

TABLE 6 | Networks and UNEP climate adaptation indicators.

Indicator	C40	CDC	UBC
Ecosystem-based adaptation (EbA)	S	S/A	S/A
Knowledge, analysis and networking	S/A	S/A	S/A
World Adaptation Science Programme (WASP)	–	–	A
National Adaptation Plans (NAPs)	S/A	–	S/A

we identified additional instruments such as: competitions and awards, collaboration with the private sector, technical assistance, training programs/webinars.

We classified the identified instruments into three categories of activities: cooperation between cities-members, collaboration (external), education and outreach (**Table 7**).

There are four major observations concerning the types of instruments the TMNs use. First, each of the 17 considered instruments is used by at least one of the networks. Second, most of the instruments are used by UBC – 17, the CDC uses only 5 of them. It should be emphasized, however, that due to the multi-thematic nature of UBC, the tools used are not only related to the issue of climate change, while in the case of C40 and CDC all identified forms and tools concern this issue. Thirdly, the least used tools are running databases, lobbying, organizing study visits and summer schools. Databases are created only by the C40, while the remaining instruments are used by UBC. Fourthly, the most popular and most frequently used instruments are: the exchange of good practices, thematic conferences/workshops, dissemination of educational materials and other publications.

Based on the qualitative analysis we would like to formulate a few comments relating to the selected instruments – those most commonly used and the ones that are particularly valuable and innovative in the context of activities related to climate change.

Exchange of Good Practices

The exchange of good practices takes place in the form of databases and publications, but also takes place during organized conferences, workshops and training seminars. The C40 has created a special website for this purpose[3]. Since 2015 the C40, in cooperation with partners (Sustainia – international think tank, Realdania – a Danish philanthropic association, Nordic Sustainability – a Copenhagen-based consultancy), issues reports such as ‘The Cities 1000’ containing 100 solutions from cities around the world on climate action. As emphasized: “The final 100 city solutions will serve as a guide to creating the resilient and sustainable urban environments of the future.” The UBC’s database of good practices is available on a blog run by the UBC Sustainable Cities Commission[4]. The CDC published good

[2] S, issues are presented in the statements and declarations; A, issues are the subject of action (programs or projects).

[3] https://www.c40knowledgehub.org

[4] http://ubcenvcom.blogspot.com/

TABLE 7 | Types of activities and applied instruments – data from C40 Cities Climate Leadership Group (C40), Connecting Delta Cities (CDC), and Union of Baltic Cities (UBC).

Type of activity	Instrument*	C40	CDC	UBC
Cooperation between cities-members:	Exchanging of good practices	+	+	+
	Thematic conferences/workshops	+	+	+
	Competitions and awards	+	−	+
	Positions/declarations	+	−	+
	Working groups/subnetworks	+	−	+
	Study visits	−	−	+
Collaboration (external):	*Collaboration with the private sector*	+	−	+
	Cooperation with other urban networks	+	−	+
	Lobbying	+	−	+
	Scientific and academic cooperation	+	−	+
Education and outreach:	Educational materials	+	+	+
	Publications	+	+	+
	Communication tools (website, newsletter, social media)	+	+/−	+
	Technical assistance	+	−	+
	Training programmes/webinars	+	−	+
	Databases	+	−	−
	Summer schools	−	−	+

**Instruments in italic were identified during the research.*

An instrument used by all three networks (green)

An instrument used by two of the three networks (light)

An instrument used by only one network. (pink)

practices in 2016 in the form of the Climate Change Adaptation in the 'Delta Cities Report. Good Practice Guide.'

Thematic Conferences/Workshops

Summits, workshops, and conferences take place on a regular basis to facilitate the exchange of ideas and best practices as well as build personal interactions (in addition to virtual ones). A flagship event for the C40 is the C40 Summit that takes place every 2 years. "At the summits, mayors present their 'groundbreaking projects,' forge strategic partnerships and announce new initiatives to the public" (Lin, 2018, p. 119). The C40 workshops are organized primarily by networks and are more focused on specific themes of a more technical nature (for example: Waste Workshop, London, March 22–24, 2010; Sustainable Communities: Collaborating, Planning, Delivering, Melbourne, March 28–30, 2012; Solid Waste Networks Workshop, Milan, October 1–3, 2014; C40 Green Growth Network Workshop, Vancouver, March 2, 2016). The CDC organized two multi-day conferences in Rotterdam entitled "Deltas in Times of Climate Change" (2010, 2014) and the workshop: The CDC Workshop (2013). The UBC organized a lot of events of different sizes and for different audiences, e.g., the UBC Climate Resilience Webinar that was held on 26 March 2019 and the UBC Sustainable Cities Commission organized a meeting entitled "Resource Wisdom and Biosphere areas in UBC cities" in Jyväskylä on 16–18 May 2017.

Educational Materials

The most elaborate of the provided educational materials are videos, electronic publications and dedicated portals, such as the C40 Knowledge Hub (see footnote 2) or the CDC Knowledge Portal[5]. The C40 also has a special tab on its website[6] where you can search for examples of effective actions taken by member cities. In cooperation with ICLEI and the World Resources Institute the C40 launched the Global Protocol for Community-scale Greenhouse Gas (GHG) Emission Inventories to support cities to measure and report city-wide GHG emissions in a robust, comprehensive and consistent way[7]. This enables cities to understand the contribution of different activities and track the impact of climate actions. Consistent with IPCC Guidelines, the Protocol also allows for a credible comparison and aggregation across timescales and geographies, which helps to inform city-wide climate strategies. The UBC does not make much general material available, but provides educational materials that are related to specific events, e.g., the UBC Sustainable Cities Commission shares materials from the webinar "Climate change adaptation through smart stormwater management" organized on 28 April 2020.

Publications

The nature of the network's publications is differentiated. The networks publish promotional and informational materials in electronic and/or paper form (UBC). There are various types of cyclical magazines published that have a different frequency (semi-annual UBC Baltic Cities Bulletin – each number is devoted to a special theme – e.g., the issue of spring 2017 was entitled "Sustainable and climate-smart Baltic Sea Region Cities."

[5]http://deltacityofthefuture.nl/knowledge-portal
[6]https://www.c40.org/case_studies
[7]https://resourcecentre.c40.org/resources/measuring-ghg-emissions

Moreover, each Bulletin covers information on the latest UBC meetings and activities, news from member cities and more. A separate Bulletin is also published by the UBC Sustainable Cities Commission: the "Sustainable Cities Bulletin"), it reports on the implementation of programs and projects (e.g., the C40 Infrastructure Interdependencies + the Climate Risks Report, Spring 2017; a UBC Report on Climate Leadership from the Baltic Sea Region Cities, October 2017), factsheets about its activities (e.g., C40 Networks. Connecting Cities to Deliver Climate Action) and thematic studies [e.g., ICLEI, C40 (2018), Data Speak Louder than Words. Findings from an initial stocktake of climate change adaptation and urban resilience efforts; Molenaar et al., 2013; CDC; Resilient cities and climate adaptation strategies].

Competitions and Awards

Interesting forms of the networks' activities are competitions and awards. Since 2013, the C40 organizes the C40 Cities Bloomberg Philanthropies Awards (Siemens was a partner in the City Climate Leadership Awards for years 2013 and 2014), which aims to recognize in cities within the scope of seven categories (e.g., The future we want engages all citizens, The future we want uses green technologies) that have implemented outstanding projects, programs, policies and practices to combat climate change, reduce climate risks and improve lives in their communities[8]. Additionally, the C40 organizes a global competition for innovative, carbon-free and resilient urban projects (e.g., Reinventing Cities). The UBC also supports the Baltic Sea Award granted to a person or an organization which has made meaningful and outstanding contributions to the Baltic Sea environment.

Cooperation With Other Urban Networks

The examined networks are open to cooperation with other TMNs. The C40 has good working relations with the ICLEI – Local Governments for Sustainability, United Cities and Local Governments (UCLG) and the Global Covenant of Mayors. The UBC is a member of the Conference of European Cross-Border and Interregional City Networks (CECICN) established in April 2010, which is an EU platform of city networks. Its objective is to boost territorial cooperation among cities with specific geographical features in Europe. The UBC has enhanced its cooperation with other Baltic Sea urban networks such as the Baltic Metropoles Network (BaltMet) and is also developing contacts with Baltic interregional networks, i.e., the Parliamentary Conference on Cooperation in the Baltic Sea Area, the Baltic Sea States Subregional Cooperation (BSSSC) and the Conference of Peripheral Maritime Regions (CPMR) Baltic Sea Commission.

Technical Assistance

Many city authorities have limited resources, and the implementation of climate actions requires significant time, money, and human resources. The networks help overcome the constraints that member cities face. Two C40 programs deserve special attention: C40 City Advisers and C40 Cities Finance Facility (CFF). C40 City Advisers are dedicated staff supporting selected member cities in the development and implementation of priority policies, programs, and projects to reduce GHGs and/or climate risks[9]. The C40 Cities Finance Facility is the result of collaboration between the C40 and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The CFF facilitates access to finance for climate change mitigation and resilience projects in urban areas by providing technical assistance to develop cities' sustainability priorities into bankable investment proposals[10].

Communication Tools (Website/Social Media/Newsletters)

All three networks are present on the Internet – have their own websites[11,12,13], and C40 and UBC also have accounts on popular social media platforms such as Facebook, Instagram, Twitter, YouTube and LinkedIn. Websites are used to inform a wide audience (not only own members) about the activities of the network and its results. They contain information about networks and their members, implemented and planned projects, organized events, and links to publications. As the member cities come from many countries, the websites are run in English and in the case of the C40 also in Chinese. Additionally, C40 and UBS disseminate various types of cyclical newsletters published with different frequency: C40 – bimonthly and UBC – quarterly.

Working Groups/Subnetworks

Working groups also serve as a forum for the exchange of good practices, experience and know-how between the network's member cities. They organize cooperation around specific issues and problems. The C40 is a specialized, issue-specific network focused on climate change issues. However, this issue is complex, hence as many as 17 subnetworks are formed around a specific topic: Air Quality; Clean Construction Forum; Clean Energy; Connecting Delta Cities; Cool Cities; Food Systems; Land Use Planning; Mass Transit; Mobility Management; Municipal Building Efficiency; New Building Efficiency; Private Building Efficiency; Sustainable Waste Systems; Urban Flooding; Walking & Cycling; Waste to Resources; Zero Emission Vehicles. The CDC is therefore one of these C40 subsets. In the case of UBC, the UBC Sustainable Cities Commission[14] is directly dedicated to (but not limited to) climate change among the seven Commissions that are in operation. Two other commissions, i.e., Planning cities and Inclusive and Healthy Cities, also deal with climate change issues, albeit, more implicitly, by using the sustainable development agenda as a guideline for their activities.

Databases

One of the existing databases is the Adaptation and Mitigation Interaction Assessment (AMIA) developed by the C40 in cooperation with the Children's Investment Fund Foundation.

[8] https://www.c40.org/awards

[9] https://www.c40.org/programmes/city_advisers

[10] https://www.c40cff.org/

[11] https://www.c40.org/

[12] http://deltacityofthefuture.nl

[13] https://www.ubc.net/

[14] https://www.ubc.net/commissions/sustainable-cities

The Excel-based AMIA tool helps cities understand the relationship between mitigation measures, which reduce greenhouse gas emissions, and adaptation measures, which reduce climate risks and helps policy-makers systemically analyze potential interactions between mitigation and adaptation as they develop climate action plans. The online library of nearly 60 case studies is regularly updated with new case studies both from C40 cities and external sources, which brings insight into the actual implementation in different environments.

The Climate action for URBan sustainability (CURB) tool is a data-driven scenario planning tool designed to assist cities in pursuing climate action across their energy, buildings, transport, waste and water systems. The Excel-based tool was developed by C40 Cities in partnership with the World Bank, the Global Covenant of Mayors for Climate and Energy (GCoM), Bloomberg Philanthropies and AECOM. Building on the Global Protocol for Community-scale Greenhouse Gas (GHG) Emission inventory data supports cities to plan a range of actions to reduce energy use, save money, and cut greenhouse gas emissions. The technology and policy actions covered by CURB can also help deliver important local quality of life benefits, including improved air quality, local economic development and job creation.

DISCUSSION AND CONCLUSION

Transnational municipal networks are an increasingly popular form of cooperation of non-state actors, and climate change issues are increasingly common areas of their activity (e.g., van der Heijden, 2018). This also applies to networks of coastal cities. But how is this potential used in relation to climate change adaptation and mitigation measures?

The results of our analysis suggest that the networks of cities implement both mitigation and adaptation measures, although, 'soft' mitigation actions seem to be the most common. For example, the C40 AMIA report includes 122 examples on actions related to mitigation, while only 57 cases relate to adaptation measures. This appears to be a well-established trend in the cities' cooperation (e.g., Mansard et al., 2017; Heikkinen et al., 2020), and the change toward adaptation has only started (e.g., Heikkinen et al., 2020). However, the level and depth of this change is difficult to assess, since practical actions occur at the individual city level, and the networking activities focus on knowledge sharing and the exchange of good practices. A similar situation was observed regarding past mitigation activities (e.g., Kern and Bulkeley, 2009; Busch et al., 2018), and yet the networks of cities are considered rather efficient in mitigating climate change (Castán Broto and Bulkeley, 2013). Therefore, it is likely that the effect of the scale that worked for the mitigation issues (Acuto, 2013; Lin, 2018) can also support the adaptation measures.

It also appears that the UBC is the network that best recognizes the importance of marine ecosystems for combating climate change. The other two networks neglect the productivity of marine ecosystems (**Table 5**) and – consequently – its health and good environmental status. This is somewhat paradoxical as the UBC is the only network that is not focused solely on climate change. This again raises the question whether this greater awareness is related to the vicinity of the Baltic Sea or to the European recognition of regional seas. Indeed, regional seas are an important element of the larger policy landscape in Europe (van Tatenhove, 2013), and the countries around the Baltic Sea are in fact pioneers and frontrunners in regional cooperation. Initiatives such the Helsinki Convention (HELCOM) or VASAB are examples of well-established cooperation efforts that greatly contribute to the governance of the Baltic Sea (Kern, 2011; Zaucha, 2014).

We believe that this specific ocean 'blindness' can be, indeed, an important challenge in combating climate change and a serious setback to the effectiveness and full participation of transnational city networks in marine governance. A good environmental status of marine ecosystems (expressed through the United Nations SDG 14 'Life below water'; Salvia et al., 2019) is an important precondition for achieving other SDGs (Nash et al., 2020), and progress toward this goal offers a great range of co-benefits (and almost no trade-offs) for other SDGs (Singh et al., 2018). In other words, actions addressing climate change cannot be successful if seas and oceans are not properly protected (Tessler et al., 2015; Gruber et al., 2019). And yet, SDG 14 is a goal that receives relatively little attention and is of low priority, and consequently does not receive enough funding at both global and national levels (e.g., Nash et al., 2020). It, therefore, does not come as a surprise that the SDG 14 ambitions will most likely not be accomplished (Nash et al., 2020), which among other results stemming from a lack of wide ocean-awareness among the stakeholders in the cities and their networks. The cities' limited awareness is most likely a reflection of the more general preferences for the other SDGs among decision-makers across various levels and scales. This may be a place for increased activities within the framework of the Ocean Literacy, since an ocean-literate person understands the essential principles and fundamental concepts, can communicate about the ocean in a meaningful way, and what is crucial in mitigation and adaptation actions, is able to make informed and responsible decisions regarding the ocean and its resources (UNESCO, 2020). Without such skills, it is difficult to comprehend the complex issues which govern climate change and its impact on the ocean and the ocean's impact on climate change (SDGs 13 and 14), thereby reducing the feasibility of achieving the remaining SDGs, which is a key task for all humans but is especially important for coastal communities. Developing Ocean Literacy among the networks' participants should also be perceived as an important step toward their greater involvement in marine governance, a shift to unlock the potential of coastal city networks in this important sphere.

In our research we confirm that the activities run by TMNs are defined and restricted by the competences granted through national laws and external (foreign) actions of cities just cannot step outside of these bounds (Dumała, 2012). *De facto* mayoral powers differ within a TMN from city to city depending on constitutional arrangements. Working out the formula and scope of its activity, networks are looking for a 'common denominator' of shared competences, which explains why the range of actions that the network undertakes does not include all climate change issues recommended in global debates, programs or documents.

Based on our results we argue that the activity of the network is more determined by the properties of the network than by the tools they used. What is more, it is the properties of the network, especially the proximity of cities to each other that influences the choice of preferred topics. The C40, CDC and UBC are spatially dispersed transnational territorial networks, so they focus on supporting flows of intangible resources, i.e., information, knowledge and experiences (Lee, 2013), mostly via the Internet.

However, we argue that this 'distance shrinking' does not eliminate the significance of geographical differences, which are still relevant for responses toward climate change. The spatial identity of the networks and their scope of activities and areas of actions do not influence any type of neither specific activities nor tools, however, they determine their substantive content. The spatial identity of cities that form networks is the foundation of their involvement. The fact that all cities are coastal cities is key to the creation of networks. However, when analyzing the positions and activities of individual networks, we did not observe that the coastal location is the leading thread behind their involvement in marine governance or their approach to climate change adaptation and mitigation. This means that cities with such problems when facing the same challenges (which results from the fact that they are located in the same region, like UBC members – Baltic Sea Region) tackle more practical issues from their point of view, mainly related to adaptation to climate change, because benefits of adaptation efforts are mostly local and regional. In turn, in the case of networks consisting of coastal cities, but scattered around the globe, more general (worldwide) issues are more convenient, allowing the adjustment of common assumptions to meet the needs of a particular place. Therefore, there are fewer joint initiatives and there is more sharing of own experiences – e.g., in the CDC.

We observed that more formalized networks (acting as associations – C40 and UBC) use a much wider range of tools. This can be explained by the functioning of a more developed administration (secretariats and others bodies) which have the financial and human resources available to coordinate and organize the activities of the network. The level of network institutionalization has less impact on the scope of their activity (in principle, all of the studied networks had the same scope, which is related to their similar functions), and more determines the number of tools used and the intensity of their use. It is clear that networks with strong structures and larger resources are more active (C40, UBC). A special case is the CDC, which in recent years – basically without a specific reason – has significantly reduced its functioning and its organizational background is minimal. The leader of a network may also play a role. In the case of the C40, such a leader was undoubtedly the initiator of the first 2-day World Cities Leadership and Climate Summit on 3–5 October 2005, the mayor of London, Ken Livingstone, the other was Mayor of New York City billionaire Michael Bloomberg. During his 3-year tenure as Chair (2010–2013) Bloomberg hired global consulting firm McKinsey to refashion the network into a fully functioning organization with full-time staff, an executive team as well as funding partners. He invested heavily in media and marketing for the C40 network and created a PR division that would promote the networks and member cities' activities through their website, TV and print and social media (Barthold, 2019). UBC also has a very well-developed institutional framework as its Secretary General has been the same person since the beginning of this network in 1991.

Soft instruments (such as conferences and workshops, exchange of good practices, educational material, publications) still dominate the activities of the analyzed networks. Importantly, the developed good practices are available not only to members of the network, but also to any interested city (or actor) via the open nature of the website where these are published. Apart from the traditional tools, there are also some more innovative tools, such as technical assistance or databases [e.g., Adaptation and Mitigation Interaction Assessment (AMIA), the C40 Greenhouse Gas Protocol for Cities Interactive Dashboard]. The innovativeness of the operation of networks such as the C40 and UBC is confirmed by earlier studies (Bouteligier, 2013b; Papin, 2020). It has been made possible, among others, thanks to the cooperation with other entities (companies and organizations) which strengthen the network's capabilities by equipping these with resources (financial and human) which these member cities and networks otherwise would not have access to. Lin also notes that C40 partnerships help overcome the constraints that member cities face, such as the limited resources needed to take climate action (Lin, 2018). Acuto confirms this opinion: "[. . .] their participation is incentivized by scale advantages that are facilitated by pooling large municipal resources, exchanging best practices models, and accessing privileged technical (and more broadly planning) services through the Group's private allies." (Acuto, 2013, p. 850). In the case of the UBC, such a role seems to be played by the European Union.

According to Kern and Bulkeley (2009) TMNs have three defining characteristics. (1) Member cities are autonomous, which means they are free to join or leave the network. (2) Due to their non-hierarchical, horizontal, and polycentric nature, they are referred to as practicing a form of self-governance. (3) The decisions made within the networks are implemented directly by their members. The third feature is, in our opinion, the difficulty of assessing the effectiveness of the network: each member city decides for itself whether and how it will implement the recommendations of the network. This is also a certain weakness of the network in terms of its direct performance. Lin (2018) affirms that to encourage the spread of norms, practices, and voluntary standards amongst member cities, TMNs have to resort to persuasion, mutual benefit, and reciprocity.

Nevertheless, the existence of a 'network effect' can be observed. For example, in the Carbon Disclosure Project (CDP) analysis we read: "On several key criteria, C40 cities outperform the overall average, suggesting that there may be a relationship between C40 participation/affiliation and higher awareness of the risks and opportunities of climate change."

(CDP and AECOM, 2012, p. 60). According to the above quotation, a comparison of the cities belonging to the network with those not belonging to them indicates the existence of 'some' network effect. In more recent studies (Heikkinen et al., 2020) the results confirm that TMN members are more likely to start the climate change adaptation planning process than other cities.

Concluding, we highlight that the TMNs due to their organizational and normative limitations and lack of well-developed ocean literacy are not able to fully engage in all the activities related to climate change adaptation and mitigations as suggested by the UNEP. The networks of coastal cities implement both mitigation and adaptation measures, although 'soft' mitigation actions seem to be the most common. While the scale and innovativeness of the networks' operations are determined by their specificity resulting from spatial identity, the effectiveness of jointly developed strategies and actions depends heavily on the available human resources and the commitment of cities.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

HD, MŁ, JP, and TZ: conceptual works and manuscript preparation. HD, MŁ, and TZ: literature review and data collection. HD, MŁ, and JP: analyses of cases and conclusions. All authors contributed to the article and approved the submitted version.

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REVIEW
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Transferring Complex Scientific Knowledge to Useable Products for Society: The Role of the Global Integrated Ocean Assessment and Challenges in the Effective Delivery of Ocean Knowledge

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The ocean provides essential services to human wellbeing through climate regulation, provision of food, energy and livelihoods, protection of communities and nurturing of social and cultural values. Yet despite the ocean's key role for all life, it is failing as a result of unsustainable human practices. The first global integrated assessment of the marine environment, produced by the United Nations under The Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects (the World Ocean Assessment), identified an overall decline in ocean health. The second assessment, launched in April 2021, although recognising some bright spots and improvements, stresses ongoing decline in the ocean as a result of many unabated anthropogenic stressors on the ocean. This highlights that society, as a whole, does not fully recognise or value the importance of the ocean to their lives and impacts on the ocean caused by human activities. Further, recognition of the need for immediate and effective solutions for mitigating impacts and enabling ecosystem recovery, and the associated societal changes required is lacking. The United Nations 2030 Agenda for Sustainable Development and the United Nations Decade of Ocean Science for Sustainable Development 2021–2030 both recognize that sustainability is both a desired and essential pathway for ensuring the ocean can continue to provide the services society depends on. The World Ocean Assessment has an important role to play in increasing awareness of the ocean, the changes occurring in the ocean, the human activities causing those changes and the progress being made in reducing and mitigating the impacts of human activities on the marine environment. This paper outlines the knowledge brokering role that the Regular Process provides on ocean issues to all aspects of society from policy makers, ocean managers, ocean users to the public. It identifies the challenges faced by the Regular Process in successfully carrying out that role and lessons learned in achieving widespread uptake and recognition. Within the Decade of Ocean Science for Sustainable Development, solutions in the form of instructions or guidelines for the use of the assessment can be developed and implemented.

Keywords: world ocean assessment, ocean literacy, science-policy interface, sustainable development goals, ocean management

INTRODUCTION

Background to the World Ocean Assessment

The ocean supports all life on Earth. It provides essential services to the wellbeing of all of humankind by regulating our climate, storing carbon, producing oxygen, providing food, mineral and energy sources and nurturing social and cultural values (Pendleton et al., 2020). It has facilitated global economies for centuries *via* trade routes and is the basis for the fastest growing economy–the blue economy–expected to contribute over US$3 trillion to the global economy over the next 10 years (OECD 2016). However, an important constraint on this growth is the ongoing deterioration of the ocean caused by the pressures already being placed on it through human use (United Nations 2017; United Nations 2021).

In 2002, leaders from government, non-governmental organisations, business and other international organisations attending the World Summit on Sustainable Development recognized that significant gaps and challenges existed in the understanding of ocean processes and trends, and in achieving sustainable outcomes for the ocean within the context of increasing populations and associated demands on its services (United Nations 2002). They agreed to increase scientific and technical collaboration, including expanding ocean-observing capabilities for the timely prediction and assessment of the state of marine environment and in doing so, establish a regular process for global reporting for an integrated assessment which should include socio-economic aspects (United Nations 2002). Importantly, it was recognized that prior to this point there had been no framework or process for providing an integrated view of the global state of the ocean (Feary et al., 2014). In initiating the Regular Process, the United Nations (UN) General Assembly launched an "Assessment of Assessments" in 2003 (UNEP and IOC-UNESCO, 2009) and by 2009 a framework for a Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects was adopted (United Nations 2010).

The first cycle of the Regular Process was conducted over 2010–2015, during which the first global integrated marine assessment (the first world ocean assessment) was produced (United Nations 2017). This assessment constituted the first comprehensive global overview of the state of the ocean and the relationships between the ocean and humans, covering environmental, social and economic aspects. This first assessment identified that parts of the marine environment, especially near the coast were seriously degraded and that there had been an overall decline in the state of the ocean. The assessment identified that the ability of the ocean to provide vital services to society, and the Earth as a whole, would continue to be reduced without an integrated, coordinated, proactive, cross-sectoral and science-based approach to coastal and marine management (United Nations 2017). The second assessment, launched in April 2021, although recognising some improvements in some sectors and some regions, also identifies ongoing decline in many aspects of the ocean as a result of the many unabated pressures humans are placing on the ocean (United Nations 2021). These findings are in line with other recent reports on the state of the Earth's climate, ocean and biodiversity (IPBES net al., 2019; IPCC et al., 2019; CBD 2020). This highlights that society, as a whole, does not fully appreciate the role of the ocean in sustaining their lives or have full awareness of the impacts of current human activities and behaviours on the ocean. It also suggests that society does not fully understand the urgent need for innovative and effective solutions for mitigating impacts and the behavioural changes required to reduce stressors on the environment and facilitate a sustainable ocean future (McCauley et al., 2019; Kelly et al., 2021; Pendleton et al., 2020). The second world ocean assessment further highlights some of the current barriers to implementing such solutions, including significant constraints on resource capacity, including financial capacity, and technological capacity. The lack of access to the required knowledge, appropriate tools and skilled human resources needed for ocean management remains a significant constraint for the protection and conservation of the marine environment in many regions. Significant effort is needed in overcoming challenges to ensuring inclusive participation of countries in international instruments, strengthening intersectoral cooperation, ensuring coordination and information-sharing at all levels and developing new instruments to address emerging challenges in a timely fashion (United Nations 2021).

Relevance of the World Ocean Assessment to International Processes

The Regular Process is facilitated by the UN Division for Ocean Affairs and the Law of the Sea (DOALOS; https://www.un.org/Depts/los/index.htm) and therefore has direct linkages with the UN Convention on the Law of the Sea (UNCLOS) which sets out the legal framework within which all activities in the oceans and seas must be carried out. It is recognized by the General Assembly in contributing to the provision of scientific information that supports the 2030 Agenda for Sustainable Development (https://sustainabledevelopment.un.org/), the development of an international legally binding instrument under UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (https://www.un.org/bbnj/), the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (https://www.un.org/Depts/los/consultative_process/consultative_process.htm) and the United Nations Framework Convention on Climate Change process (https://unfccc.int/). In doing so, the Regular Process aligns with the activities of the Convention on Biological Diversity (CBD; https://www.cbd.int/), the Intergovernmental Panel on Climate Change (IPCC; https://www.ipcc.ch/) and the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES; https://ipbes.net/). Key outputs from processes such as those conducted by the IPCC and IPBES, as well as those produced through reporting mechanisms associated with various conventions such as those under the International Maritime Organisation (https://www.imo.org/en/About/Conventions/Pages/ListOfConventions.aspx) and international and regional commissions such as those of the International Union for Conservation of Nature (https://www.iucn.org/about/union/commissions) are integrated into the World Ocean Assessment and there has been an exchange of contributors across reports produced by each. Importantly, the Regular Process provides primary information specifically relating to the ocean that is either under-represented or missing from these outputs, particularly as a result of the interdisciplinary approach to the assessment and inclusion of social and economic aspects, and therefore provides a mechanism for informing initiatives carried out by these bodies.

Important outputs from the first cycle included three technical abstracts that distilled the content of the first assessment into useable information focused around climate change, biodiversity in areas beyond national jurisdiction and the sustainable development goals (SDGs), in particular, SDG 14 Life Below Water. The content of the first assessment itself and the series of technical abstracts raised the profile of the declining state of the ocean both within the UN and beyond and is recognized as informing action on SDG14 (Fawkes and Cummins 2019). This first assessment has been recognized as informing the development of a proposal to the UN General Assembly by the Intergovernmental Oceanographic Commission (IOC) for a Decade of Ocean Science for Sustainable Development (an "ocean decade"). This ocean decade was proclaimed by the UN in 2017, began in January 2021 and will run through to the end of 2030 (www.oceandecade.org). The implementation plan for the ocean decade identifies an overarching aim "to catalyse transformative ocean science solutions for sustainable development, connecting people and our ocean" (IOC-UNESCO 2020).

The World Ocean Assessment has the potential to provide a benchmark reporting mechanism for this ocean decade and the success of efforts conducted under the decade in reversing declines in the state of the ocean and its ecosystems and transforming human use to sustainable practices. The second World Ocean Assessment provides an overview of the state of the global ocean at the start of the ocean decade, the third World Ocean Assessment to be delivered in 2026, has the potential to provide a mid-way report and the fourth World Ocean Assessment, to be delivered after the finalization of the ocean decade could provide an overview of change that might have occurred as a result of the efforts conducted throughout the decade. These assessments could also provide a mechanism for identifying where knowledge and capacity gaps remain and where efforts made during the decade need to be focused.

Here, we outline the knowledge brokering role that the Regular Process provides on ocean issues, the challenges faced by the Regular Process in successfully carrying out that role, lessons learned during the first assessment in achieving widespread uptake and recognition and potential solutions that could be implemented in future assessments.

OCEAN AWARENESS AND UNDERSTANDING AND THE ROLE OF THE WORLD OCEAN ASSESSMENT

The Need for Increasing Awareness and Understanding and Challenges

Key to achieving the targets of the SDGs and in particular, those of SDG14 and the aims of the ocean decade, will be improving societal overall awareness and understanding of the ocean. This will require all parts of society (from communities to business to government) understanding and being capable of discussing the role of the ocean in supporting life on Earth, the reliance of society on the ocean for provisioning services and wellbeing and the impacts of current human behavior on the ocean [i.e. improving ocean literacy; see Schoedinger et al. (2010), Kelly et al. (2021) for a comprehensive overview of current approaches to ocean literacy and steps for improving ocean literacy]. It will also require society to then utilise that understanding to undertake informed decision making and implement behavioural changes required to halt and reverse impacts on the ocean (Schoedinger et al., 2005; Fauville et al., 2019).

One of the key challenges in engaging society with the ocean, is a lack of connectedness to the ocean. Although nearly 2.5 billion people live within 100 km of the coast (UNDESA, 2019) and coastal regions are experiencing higher rates of population growth and urbanization than inland regions (Neumann et al., 2015), much of the world's population only spend a limited part of their life experiencing ocean environments (Cigliano et al., 2015). Increasing urbanisation is resulting in reduced access to the ocean (Roy et al., 2018). Modern lifestyles and technologies are leading to people spending time indoors rather than outside in the natural environment (Basile, 2016; Truong and Clayton, 2020), leading to a movement away from and a loss of cultural practices that might connect people to the ocean (Komugabe-Dixson et al., 2019). This disconnectedness is strongly associated with poor awareness and understanding of ocean issues (McKinley and Fletcher 2010). Personal connectedness builds a responsibility or value system that is crucial in the process of behavioral change since knowledge and awareness are usually not sufficient for establishing a change in attitudes (Stoll-Kleemann, 2019).

In order to address these challenges and create the societal behavioural changes required for a future healthy, productive and sustainable ocean, innovative ways to share information and build knowledge and connectedness are needed. Effective connections between knowledge generators, including those in formal areas such as researchers, engineers, scholars, as well as less formal areas such as traditional owners, indigenous and first nations peoples with business, industry, government and all sectors of society will need to be built (Pendleton et al., 2020). Overall ocean literacy needs to be raised across all parts of society, including those making decisions that affect the ocean (Kelly et al., 2021). Extending ocean literacy programs and integrating these into school curricula across the world, coupled with the inclusion and nurturing of natural spaces in schools will assist with building a generation that values the ocean. Importantly it will engender an increased awareness in the next generation of decision makers, business leaders and societal catalysers.

The World Ocean Assessment: Provision of Information

The main outputs of the Regular Process, the World Ocean Assessments, provide a pathway for the sharing of ocean information and knowledge with society and provide both a global perspective on the current state of the ocean as well as more focused regional perspectives. During each assessment cycle, teams of volunteer experts including ocean scientists (across the fields of natural sciences, economics and humanities), managers, regulators and policy makers are brought together to provide such perspectives on key topic areas ranging from the state of species and habitats, ocean industries and ocean science, ocean values and community connections and planning and management approaches. Each team is tasked with synthesising current published and publicly available information to provide the state and trends of important ocean features and values over time, use of ocean environments by society and impacts created by that use (Evans et al., 2019). Further input into information gathering and development of content of the assessment by a wider group of scientists, managers, regulators and policy makers is facilitated through regional workshops, a stakeholder dialogue, a peer review process and then review by the member states of the UN. Through this process, the assessment serves the purpose of distilling complex, technical information on a wide range of ocean topics from many sources, information that is often beyond the reach of decision makers and the majority of the public population, and present it in formats that can be utilized more broadly. Production of technical abstracts (produced in association with the first assessment) and policy-relevant briefs, webinars and a web series of short expert interviews (being produced in association with the second assessment) allow for information focused around topical issues to be further distilled and provided in short formats for easier access and use. Through the production of regular assessments, with succeeding assessments focused on providing information on change since the previous assessment, the regular process provides information on how the ocean is changing, in what way and at what speed that is regularly updated through time.

Early assessments of the reach of the first world ocean assessment have identified that its' content has primarily been used for coastal and marine research, academic purposes, including input into curricula, policy development and awareness raising activities (Fawkes and Cummins 2019). Further, the workshops conducted as part of the first cycle have been identified as facilitating connections and collaborations between ocean disciplines (Fawkes and Cummins 2019). Information from the first World Ocean Assessment has been summarized across many media platforms and features on the websites of UN agencies (e.g. https://ioc.unesco.org/our-work/first-world-ocean-assessment), national, regional and international ocean focused programmes (e.g. https://pipap.sprep.org/content/first-world-ocean-assessment-united-nations), and ocean information and communication initiatives (e.g. https://worldoceanobservatory.org/index.php?q=content/un-world-ocean-assessment; https://www.grida.no/publications/314). At the time of writing, just after the launch of the second world assessment, information has already been distilled and featured by a number of research programmes (https://www.futureearthcoasts.org/second-world-ocean-assessment/), agencies (e.g. https://ecos.csiro.au/second-world-ocean-assessment-is-afloat/) and sustainability initiatives (e.g. https://www.msc.org/media-centre/news-opinion/news/2021/04/21/5-things-we-learned-from-the-un-world-ocean-assessment-ii-report).

The assessments carried out under the Regular Process, at this point in time, do not actively implement recognized drivers influencing ocean awareness and understanding [described in Kelly et al. (2021)], including education, cultural connections, technological developments and knowledge exchange and science-policy connections. However, they do provide key resource tools along with the associated abstracts and policy brief and web series, that can be employed as part of frameworks aimed at improving ocean awareness and understanding (i.e. provides an important component of the toolbox for ocean literacy outlined in Kelly et al., 2021). In providing such a resource, the Regular Process facilitates a bridging of the science-policy interface by collating and distilling technical scientific and industry knowledge into accessible and understandable formats (Bayliss-Brown and Ní Cheallacháin 2016; Fernández Otero et al., 2019).

IMPROVING THE VALUE AND REACH OF THE WORLD OCEAN ASSESSMENT–CHALLENGES AND LESSONS LEARNED

The Regular Process, having just launched its second World Ocean Assessment, can still be regarded as a relatively new undertaking, particularly when compared to other global assessments such as those produced by the IPCC, established in 1988 [see Agrawala (1998)] and in the process of producing its sixth assessment report. The Regular Process has been constrained by many of the challenges faced by the IPCC across its first two assessments, including budgetary limitations (there was no specific budget assigned to the Regular Process in its first cycle), insufficient mechanisms for facilitating the assessment, differing levels of disciplinary and regional coverage and cohesion across chapters, and varying levels of community awareness and credibility (Agrawala 1998; Fawkes and Cummins 2019). As has been the case with the IPCC, there are lessons to be learned from both the first and second cycle of the Regular Process that can be used to further improve future assessments, particularly the contribution of the assessment to bridging the science policy interface and improving societal ocean awareness and understanding.

It is widely recognized that when assessments are carried out over recurrent processes, there are useful opportunities for learning from past experience to improve procedures and enhance the effectiveness of those assessments in bridging the science policy interface (Siebenhüner 2002). The Regular Process has built a process of capturing some of the lessons learned during each cycle in an effort to improve the process and subsequent assessments. In the first cycle this comprised input from Member States of the UN, participants in the Ad Hoc Working Group of the Whole (the body that oversees and guides the Regular Process comprised of UN Member State representatives), the Secretariat to the Regular Process (DOALOS) and the joint coordinators of the Group of Experts to the Regular Process (the group that coordinates and is responsible for the writing of the assessment). This was expanded in the second cycle to also include feedback from the writing teams and peer reviewers involved in the second World Ocean Assessment. Based on the feedback provided through this process, there are three areas where improvements could be made to enhance the role of the World Ocean Assessment in increasing overall societal ocean awareness and understanding and bridging science-policy gaps.

Strengthening of Credibility Within the Ocean Community

In linking scientific information to policy decision making, assessments must be both credible and relevant (Keller 2010). The broad scope of the World Ocean Assessment, particularly in providing an interdisciplinary approach that includes not only environmental, but also social and economic aspects of the global ocean combined with the voluntary nature of contributions presents clear challenges in attracting experts not only to identify themselves to the Regular Process, but also to actively contribute to chapters throughout the Process. The Regular Process also relies on Member States to identify and nominate experts. In many cases this is managed either by representatives to the UN or associated government agencies, many of which are not adequately linked to the scientific community or don't have sufficient understanding of the interdisciplinarity required for effective facilitation of the assessment. This has resulted a lack of awareness of the Regular Process within the wide expertise it needs to engage with (scientists from many disciplines, economists, engineers, managers, regulators, policy makers) and a lack of clarity of the processes for input by these communities. As a consequence, writing teams contributing to both the first and second World Ocean Assessment have often been uneven in their disciplinary and regional coverage. An outcome of unbalanced contributions to writing teams is that chapters have varied in their scope, the degree to which they have covered the diverse range of topics and the extent to which complex scientific information was integrated across disciplines and delivered. This has led to varying perceptions of overall legitimacy and credibility amongst the ocean community (Fawkes and Cummins 2019). While similar variable contributions were noted in the first IPCC assessment (Siebenhüner, 2002; Hirst, 2014), other assessments such as IPBES have largely been successful in developing multi-disciplinary teams (Beck et al., 2014), particularly when well resourced.

Efforts to ensure greater participation in the writing teams have included an expansion of the number of workshops conducted throughout the process, the focusing of a proportion of the workshops around specific topics of the assessment and inclusion of a small number of meetings where writing teams were brought together to work on parts of the assessment. However, there is still insufficient participation in writing teams by experts from a number of disciplines, particularly in social sciences, public health, psychology, philosophy, economics and specialists directly involved in marine industries. Further, there is a lack of involvement of local, traditional and indigenous knowledge holders who can provide essential perspectives to many ocean issues and important inputs into assessments.

Improved outreach and stronger linkages with international and regional science organisations, regional seas management bodies and local, traditional and indigenous groups as well as greater engagement between member state representatives with the wider ocean communities within countries would likely assist in improving engagement in the regular process and filling these gaps. Enhanced opportunities for capacity development and mentorship of contributors from less developed regions and small island developing states through mechanisms such as internships (either through country partnerships or facilitated through regional organisations) would also serve to address current regional gaps in contributions to assessments, while also serving to increase awareness of the Regular Process throughout those regions, both within the scientific community and also more broadly. This will require a commitment from the member states to support and facilitate such mechanisms for engagement. Recognising that the majority of contributions made to the world ocean assessment are voluntary, greater support by research institutions and agencies in facilitating the involvement of experts across disciplines in assessments would assist in improving participation. Focusing the assessment process to take on more of a multi-stakeholder approach, an approach that has been central to the IPBES process [see Beck et al. (2014); Borie and Hulme (2015)], could serve to build multidisciplinary and multisectoral teams, ensure that connections for delivery of interdisciplinary information from assessments are directed appropriately and that information is delivered in readily understandable formats. This would also serve to build improved internal accounting of content comprising each chapter of the assessment, complimenting more formal review processes undertaken through peer review and member state review and improving the credibility of the Regular Process. Understanding and implementing those processes that have been successful in bringing multi-disciplinary teams together would also go some way in addressing this challenge.

Enhanced Engagement of Managers, Policy Experts, Decision Makers and Member States in the Regular Process

Member states identified during the lessons learned process associated with the first World Ocean Assessment that the assessment should "provide a reference platform for facilitating practical implementation of ocean-related sustainable development goals (SDGs) of the 2030 Agenda for Sustainable Development, support policy development at national regional and global levels and provide knowledge to effectively manage human activities affecting the marine environments." The broad scope of the World Ocean Assessment and the multi-disciplinary (physical, biogeochemical, biological, socio-ecological components) and multi-sectoral (industrial, societal, regulatory components) knowledge needed to provide a comprehensive assessment that addresses all of the needs identified by the member states poses multiple challenges to those involved in each assessment. Creating writing teams capable of comprehensively tackling each topic is one challenge (as outlined in *Strengthening of credibility within the ocean community*). Accessing relevant information at both global and at regional scales that captures current approaches, concepts, developments and understanding and then presenting that information in formats useful for decision makers is also a challenge. Most ocean observation networks do not extend into economic, social and cultural aspects of the ocean and as a consequence, sustained observations of these aspects of marine systems in harmonised formats are lacking (Evans et al., 2019). Further, much of the information associated with maritime industries is not made publicly available. Compiling economic, social and cultural information for synthesising at global scales requires considerable effort, often beyond the ability of those involved in contributing to assessments under the Regular Process (Evans et al., 2019). Identifying mechanisms for expanding ocean observing systems was highlighted by Evans et al. (2019), with the Regular Process taking on a guiding role in the development of essential (and practical) indicators that could then deliver this information through the World Ocean Assessment.

Co-development and delivery of assessments undertaken by writing teams with managers, regulators and holders of maritime industry and business data would assist not only in addressing these challenges, it would also increase awareness of the Regular Process with these sectors and assist in strengthening links between assessments and decision makers and industry; i.e. those implementing the ocean-related SDGs. To achieve this would require agreement from member states that the role of stakeholders such as maritime industries, industry regulators and marine managers is enhanced and greater engagement by member states in identifying relevant contributors from these sectors, as well as facilitating access to currently unavailable datasets. This will require some consideration of trade-offs between a desire and need for broad participation and for scientific integrity and credibility (Beck et al., 2014), but is essential for strengthening assessments to deliver the information the member states themselves are calling for. Recent voluntary commitments made by governments to ocean issues (e.g. those made at the Our Ocean and UN Oceans conferences) and a commitment to identifying actions for ocean sustainability (e.g. through self-organised initiatives such as the High Level Panel for a Sustainable Ocean Economy; see https://oceanpanel.org) suggest an increasing awareness and commitment to ocean-related processes and initiatives (Neumann and Unger 2019). Further, there is greater awareness of the need to make all data and information collected on the ocean (including historical information and that collected by governments, industry and private companies) accessible (Evans et al., 2019). There are efforts currently being undertaken to recover historical information and digitize those data for use in ocean modelling efforts (e.g. the RECovery of Logbooks And International Marine (RECLAIM) data project, https://icoads.noaa.gov/reclaim/), independent efforts to harness and deliver ocean data across users (e.g. https://www.oceandata.earth/) and government driven efforts to ensure public availability of ocean data (e.g. https://portal.aodn.org.au/) that are improving the availability of ocean information. However, much more is needed in order to ensure that ocean knowledge is widely available and comprehensive and timely assessments of the ocean that are relevant and effective for decision making can be achieved.

Improved Information Delivery Mechanisms

The first World Ocean Assessment consisted of nearly 1,000 pages of information published in English and delivered at the UN Oceans Conference (United Nations 2017). A summary of the assessment was presented separately to the UN General Assembly in all of the official languages of the United Nations (available at https://www.un.org/regularprocess/content/first-world-ocean-assessment). At the time of its release, individual chapters of the assessment and a compiled group of its component chapters was made available electronically on the DOALOS website (https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/woacompilation.pdf). The full assessment was not available in languages other than English and an indexed, searchable electronic version of the assessment was not available, somewhat limiting the potential widespread distribution and use of the assessment. Utility of multiple electronic platforms for awareness raising and production of material in easily understandable and useable formats was lacking. This was largely a consequence of the limited resources available to the Regular Process that could be put towards not only making the assessment more broadly available but also communicating the assessment beyond the UN (Fawkes and Cummins 2019; see also https://undocs.org/A/70/418). There were clear gaps in outreach and awareness raising that were raised in the lessons learned identified in relation to the first assessment.

While financial constraints on the Regular Process remain and continue to be raised in lessons learned processes, efforts to improve information delivery to wider audiences implemented for the second World Ocean Assessment, include translation of the full assessment into all official UN languages and greater utilisation of electronic platforms for delivery of key messages, particularly through targeted short form webinars and web-series. In order to improve overall awareness and the utility of the World Ocean Assessment and in association transfer of knowledge for building ocean awareness, greater and expanded efforts beyond these are required and have been raised in the lessons learned from the second cycle of the Regular Process. Efforts to improve communication and outreach proposed for the third cycle include engaging specific communications expertise and development of an outreach and engagement strategy. Any strategy that is developed should consider moving beyond older models of learning such as the "knowledge deficit model" approach (i.e. which assumes that one-way communication of information infers uptake and application of such information) (Hecker et al., 2018). Creating experiential learning opportunities that can engender strong connections of society to the ocean through greater use of technologies and story-telling approaches (Kelly et al., 2021) would improve overall awareness of the content of assessments. These could take the form of for example short video vignettes (e.g. those produced as part of the I Live By The Sea International Youth Photo and Film Contest http://www.todaywehave.com/CONTEST.html), media commentaries (such as those published by The Conversation https://theconversation.com/au), exploratory games (e.g. the board game Ocean Limited https://www.ocean-limited.de/), modules for integration into school curricula (e.g. those provided by the Monterey Bay Aquarium https://www.montereybayaquarium.org/for-educators/teacher-professional-development/teacher-programs/) or components of art or museum exhibits (e.g. national science week https://www.scienceweek.net.au/). Ensuring the information delivery is tailored in such a way that it incorporates and is respectful of local practices and knowledge-making traditions (Weichelsgartner and Marandino 2012) will be essential for expanding the reach of the assessment.

While the aim of the assessment is to provide a global overview, it is also essential that region specific information continues to be incorporated into the assessment so that it meets the needs of regional, national and sub-national decision makers and provides information that is relevant to local communities. This requires having a good understanding of the information needs of those decision makers across relevant scales. Delivery of information *via* platforms that are co-designed with decision makers, and therefore deliver information in formats that are readily interpretable and useable for developing policy and for marine management purposes, would also improve greater widespread uptake of information contained in assessments. This may require the World Ocean Assessment partnering with specialist scientific knowledge translation and brokering agencies across a range of scales (regional, national sub-national) to facilitate effective transfer of information and ensure adequate communication and uptake of information products.

CONTRIBUTING TO A SUSTAINABLE FUTURE

With the recent delivery of the second World Ocean Assessment, planning for the third cycle and delivery of a third assessment has begun. In association, further improvements that might be implemented as part of the programme of work are being considered (some of those that have been identified and/or are in the latter stages of development have been detailed above). Achieving the improvements outlined here will no doubt be an iterative process (as it has been in other global processes elsewhere), but will require improved commitment to supporting the Regular Process as well as enhanced and engagement by member states in order to facilitate. This will require improved information flows between member state representatives and the greater ocean community in order to improve interdisciplinary engagement in assessments and delivery of outputs of the Regular Process. It will also require a commitment to facilitating Findable, Accessible, Interoperable and Reusable (FAIR) data practices across institutions, government agencies and industries to ensure transparency of information incorporated into assessments and that data and information considered is comprehensive. It may also require refocusing or adapting assessments to ensure appropriate delivery of relevant information for decision making, changes also undertaken in other global assessments [see (Beck 2011)]. Again, member states will need to be open to supporting adaptation of the Regular Process in order to facilitate the delivery of the platform they have called for as part of lessons learned. Finally, it will require a commitment to innovate delivery mechanisms to ensure that information from assessments reaches out to society and is effective in improving ocean awareness and understanding.

Over the next decade (2021-2030), the UN has proclaimed a Decade of Ocean Science for Sustainable Development as well as a Decade of Ecosystem Restoration (see www.decadeonrestoration.org), identifying that substantive improvements need to made in relation to human use of the ocean and associated ecosystems if we are to continue to derive the benefits they provide to humankind and achieve the goals of the 2030 Agenda for Sustainable Development. Both of these calls to action provide an opportunity to improve understanding, innovate tools for assessing ocean environments both today and in the future, and identify solutions for mitigating pressures and repairing ecosystems. They also provide opportunities for expanding awareness of the ocean and the solutions (including behavioural change) needed to ensure a sustainable future. The knowledge brokering potential of the Regular Process in translating and transferring ocean information from generators to decision makers and to society has an essential role to play in expanding awareness of the ocean, delivering essential information that can be used for enhancing the sustainable use of ocean. Establishing clear linkages between the Regular Process, the two UN decades and other global processes (e.g. such as IPCC and IPBES) will be essential for achieving this potential. As identified in *Relevance of the World Ocean Assessment to international processes*, the World Ocean Assessment has a potentially important role in communicating and delivering ocean understanding built during the UN decades, but also serving as a mechanism for tracking the implementation of changes needed in order to support future sustainability and identifying where knowledge and capability gaps remain. Much of the ocean understanding needed to support the commitments of the High Level Panel for a Sustainable Ocean Economy can be delivered through the World Ocean Assessment and similarly the World Ocean Assessment can provide a mechanism through which the success of the commitments made can be monitored through time. Strengthening linkages with other processes (such as IPCC and IPBES) would serve to ensure that each of the processes are informative to one another, resources such as access to experts are shared and in doing so the efficiency of support mechanisms for engagement is maximised, repetition of efforts are reduced, key messaging and directives for action are aligned and the potential for co-delivery of products and associated impact is enhanced.

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KE and TZ developed the concept for the manuscript. All authors contributed to the writing of the manuscript.

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Attitudes Towards the Polar Regions as a Reflection of the Sense of Responsibility for the Environment. Theoretical Background for Further Study

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The last two hundred years in the recent history of the Earth have been a period dominated by rapidly increasing human activity. Today, the discussion on the effects of anthropopressure takes the form of critical reflection on the negative impact of humanity on the natural environment. Although sparsely populated, the effects of this impact are particularly visible in the polar regions. The consequences of anthropopressure take the form of melting ice caps and glaciers, warming and thawing of permafrost, changes in sea ice structure, erosion of sea coasts, changes in the scale of Arctic fauna and flora, and a warmer climate. Research conducted in the US shows that its citizens have knowledge about polar regions, but that the level of this knowledge is low. The scope of general knowledge, the level of education, and social and demographic features (age, gender, income) may influence the formation of social opinions reflected in legislative and political solutions concerning the polar regions. Social science research has already shown that changing people's attitudes is much more effective if the process starts in adolescence, at the beginning of institutional education. In such a situation, diagnosing the attitudes of young citizens toward polar areas is important for their further development, especially if these attitudes are to be treated as a reflection of wider attitudes toward the natural environment. In this article we set forth to review how attitudes related to the polar regions, may be used as an example of general mechanisms of changing attitudes towards the environment in general. We provide analysis that can be used as background for designing empirical research and further – for designing educational and social plans promoting environmental responsibility.

Keywords: polar regions, environment, education, consciousness, attitudes

INTRODUCTION: ANTHROPOCENE AND ANTHROPIC PRESSURE

The last two hundred years of Earth's history have been dominated by rapidly increasing human activity (Wilson, 2012; Pyron, 2018; Safina, 2018). Nowadays extensive consequences of this human influence on the natural environment are defined as the new geological era of the Anthropocene (Lewis et al., 2015). The critical phenomenon of anthropopression within the human and social sciences emphasizes the negative influence of human species on the environment, also causing climate change. This kind of approach is also shared by natural scientists, such as the chemist and Nobel Prize laureate, Paul Crutzen, who coined the term Anthropocene (see also: Zalasiewicz et al., 2010; Steffen et al., 2011). It is significant that, as an employee of the Oceanography Institute at the University of California in San Diego, he recognized the immense impact of humans on the natural environment. His concern about destruction caused by humans in nature is shared by representatives of other sciences (Safina, 2018).

Braidotti (2013), one of the most prominent thinkers in contemporary humanistic discourse on humans and their role in ecosystems, has proposed a new approach for understanding the relationship between human culture and the natural environment. Instead of contrasting these two notions, Braidotti initiated thinking about those terms as two ending points on the same continuum. This approach connects culture with nature and emphasizes the impossibility of drawing an absolute distinction between those two. Such a way of thinking is strongly related to Arne Næss's "deep ecology," in which he argued that a true understanding of nature is based on biodiversity treated as an autotelic value (1989). It is Næss who, in probably the most evocative way, emphasized that it is impossible to divide culture from nature, as both overlap in many areas (see also Wilson, 1988).

Deep ecology is related to the serious concern about the natural environment with which humans have to maintain links to fulfill one of the specific human needs – biophilia. This notion describes the human need to stay in touch with "bios". Wilson (1984) and Wilson (2011), following the initial idea proposed by Fromm (1980), became one of the strongest advocates of preserving biodiversity on earth (2016). By proposing to protect half of the planet from human access, he hopes to maintain the planet's natural resources in a sustainable way.

Purdy (2015), argued that nature no longer exists as separable from humanity. The world we inhabit is the world we have made, and it is no longer pure. Enter the Anthropocene, the age of humans, as geologists have called this planetary epoch. Purdy argued that the challenge we face as humanity is that we either have to develop environmental politics that are more democratic or accept that they will become more unequal and inhumane. To avoid the last alternative, we need to better understand the relationship between humans and nature—our environment—as our encounters with nature are not natural, but culturally and socially produced (Purdy 2015: 14).

In general, many authors hihlight the need for immediate human action toward environmental protection (Madsen, 1996; Leshner, 2005; Grimmette, 2014). Following these calls, many symbolic and very significant actions appear (e.g., climate strikes by Greta Thunberg or Nobel Prize in literature for the Polish environmental activist Olga Tokarczuk), but there is still a need to educate the broader audience about the urgency of the situation. Due to their specificity, the polar regions can be treated as litmus paper, indicating current interest in sustainability and effective environmental protection.

Before we proceed with our focus on attitudes, it is necessary to engage briefly with research on environmental communication and visualization of climate change. Environmental communication campaigns aiming at increasing awareness regarding climate change were conducted from the 1990s (see: Sakellari, 2015; Christensen and Nilsson, 2017), in which polar bears became 'icons' (Born, 2019). Research indicates that specific cultural connotations of the Arctic – especially in the US – may stand in the way for accepting the general scientific agreement related to climate change (Stenport and Vachula, 2017), that media's visualization of climate change affect ecological citizenship (Lester and Cottle, 2009), and how communicators can deploy strategies to engage with audiences to change public attitudes (Bolsen and Shapiro, 2018). While the above is certainly fruitful, our take is somewhat different as we consider how attitudes may be considered from a sociological perspective, e.g., through the formation of attitudes at an early age.

CHANGING ENVIRONMENT OF POLAR REGIONS

Evidently, climate change is an issue that concerns many citizens, especially in the countries that develop programs raising awareness regarding global warming and its negative influence on the polar regions, especially in the Arctic. This is especially true in Canada, where 88% of respondents express concern regarding climate change in the Arctic[1]. Some of the research conducted in Finland indicate that gender, knowledge about climate warming and constructive hope become predictors of attitude towards climate change (Ratinen and Uusiautti, 2020).

Although the current human presence in the Arctic and Antarctic is limited due to harsh climate conditions and difficult access, polar regions are still highly affected by human activity. The polar regions (frigid zones) of the Earth are the regions of the planet that surround its geographical poles (the North and South Poles). They are distinguished based on the amount of solar radiation received, which is significantly lower than in other regions, resulting in lower mean temperatures. This strongly limits fauna and flora in polar regions. Some authors also claim that human activities within the Arctic are, in fact, not very intense but very influential (Huntington et al., 2006). Their analysis suggests that those activities may have a larger influence on the arctic system than previously thought. This should be given special consideration, as human influence could increase substantially in the near future (McFadyen, 2011). The condition in polar regions is strongly connected with climate change and anthropic pressure in other parts of the world (ACIA, 2005). The climate and general environmental situation in the Arctic have changed significantly in the past decades. Symptoms of those changes are clearly visible in melting sea-ice cover and glaciers, melting permafrost, changing ocean currents and circulation, erosion of the sealine, change in fauna and flora of the Arctic (Arctic Biodiversity Assessment, 2013 p.675), and rise

[1]See: https://davidsuzuki.org/wp-content/uploads/2017/09/focus-canada-2014-canadian-public-opinion-climate-change.pdf or https://environmentjournal.ca/climate-change-remains-the-most-critical-issue-for-canadians/.

of temperatures (Serreze et al., 2000; ACIA, 2005; Huntington et al., 2006; Overland et al., 2019). The melting and retreat of Arctic tidal glaciers and ice disappearance from the coast (fast ice, ice foot) are the two most conspicuous effects of a warmer climate on Spitsbergen in the European Arctic (ACIA, 2005). The deglaciation of Spitsbergen causes the formation of new habitats that were not previously available. The observed changes are an increase in biomass and biodiversity and the emergence of sublittoral communities in shallower waters, where ice scouring was a controlling factor (Weslawski et al., 2010).

One would expect that the more and more intense, visible, and radical changes in polar regions caused by human activity would raise concern and provoke society to change its attitudes toward natural environmental protection. This is especially important as a massive change in society's use is anticipated to take place in polar areas—such as commercial development (fishery, shipping, logistics) and the development of tourism to areas previously inaccessible for the wider public. We thus ask: What is the role of knowledge about and attitudes toward polar regions when it comes to shaping an understanding of responsibility for the environment in these regions?

SOCIAL CONSCIOUSNESS, KNOWLEDGE, AND CONCERN ABOUT POLAR REGIONS

Research in the US shows that polar knowledge proves to be limited, but certainly not absent among survey respondents. Polar knowledge, general science knowledge, and education, together with individual background characteristics (age, sex, and income), may allow the prediction of policy-relevant opinions (Hamilton, 2008). Although polar regions are out of reach for the average citizen, their presence in reports on climate change becomes increasingly visible, which also increases media presentations on this topic. The general situation in polar regions is significantly influenced by industrial investments: gas and petroleum extraction and animal industrial production (especially fish farming) in the Arctic, and the development of tourism in both the Arctic and Antarctic. All these processes increase social, political, and economic interest in the polar regions. Scientific research conducted in the Arctic and the Antarctic has become important in detecting climate change, and the results of that research are therefore important. Popularization of research findings may increase awareness related to climate change and environmental protection. Sociological analysis indicates the following:

> "Large majorities of respondents express at least some concern about the polar consequences of climate change, even those with no direct impacts on mid-latitude life. Levels of concern are highest regarding the apparent risks of sea-level rise and coastal flooding (70% would be bothered "a great deal") or polar ice melting (63%). Somewhat fewer would, more altruistically, be bothered a great deal by threats to the Inuit way of life (45%), polar bears (45%) or seals (43%)" (Hamilton, 2008).

Thus, people who evaluate their own knowledge as being of a higher level are much more concerned about climate change in general. American surveys of public opinion often find that concern about the environment is higher among young, female, or well-educated respondents and lower among those self-identified as conservative (Hamilton, 2008; Hamilton et al., 2012). These polarized results also, for the most part, agree with the meta-analysis findings of Allum et al. (2008). This kind of research has not been conducted in Europe; although IPCC reports indicate the need for extensive socio-economic analysis of social processes leading to climate changes (Larsen et al., 2014; Hoggan and Grania, 2016 p.249).

Initial surveys conducted by us in Poland on youth aged 16–17 in 2020 aimed to identify whether there was an interest in topics related to climate change and polar regions (the youth was reached by high school teachers recruited by snow-bal method. Students were asked only one question if they do recognized the name of Greta Thunberg). The marker was determined as the level of awareness of who Greta Thunberg is. As a young activist, she could be treated by youth as a person closer to their generation's reality and identity. In the group of 136 students, 45% indicated that they are not familiar with the name of Greta Thunberg, 30% of students have recognized her name and claimed they like what she does, 15% of students recognized her name and claimed they did not like what she does, and 9% of students answered they do know who Greta is, but they had no opinion about her actions. This raw data show an interesting division of opinions among young people.

Hamilton et al. (2012) indicated that public knowledge about the polar regions, as assessed by the General Social Survey, significantly improved between 2006 and 2010—before and after the International Polar Year (2007–2008 was an extensive interdisciplinary scientific program aiming at researching opportunities offered by the unique environment of the Arctic and the Antarctic regions). He noticed however, that, increase in knowledge did not correspond with the level of concern, although in general, those who possess a higher level of knowledge (also knowledge about polar regions) tend to be more concerned about environmental protection. Hamilton's research is based on data gathered almost a decade ago, so although those results can indicate how the knowledge-concern relation can look today, it seems necessary to double-check the current relationship between those two.

In Hamilton's research, respondents were asked to assess the level of their own knowledge on polar regions. They were asked questions, such as: "Is it true that ice cover of the Arctic decreases?" and "Does the number of polar bears decrease?". Young adults, more educated persons, and those holding liberal political views were much more worried about environment. On certain environmental topics, women expressed greater concern than men. Research on the social bases of concern about climate change, in particular, has looked closely at the roles of education and knowledge, including how these are filtered by ideology or preexisting beliefs (e.g., Madsen, 1996; Leshner, 2005; Mikulik and Babina, 2009).

Knowledge of polar regions can be treated as an indicator of general attitudes toward environmental protection. Polar regions possess certain characteristics that can allow for such a generalization.

First, polar regions are distinctive in their landscapes, climate, fauna, and flora (Tin et al., 2012). Those elements become iconic, and they become representatives of much wider processes (polar bears represent mega-fauna being extinct; glaciers represent reservoirs of water for the planet; melting sea ice cover represents global warming; and empty snowing landscapes represent mindfulness and calm). Therefore, social awareness about preserving those elements should be expected to be higher than awareness about regions with less distinctive elements.

Second, many countries have vested interests in the polar regions and are involved on different levels, as seen through not only the membership of Arctic eight countries in the Arctic Council, but also the interest of non-Arctic states observer states in the Arctic Council (Loukacheva, 2015). The international presence of research stations at Svalbard is a further example. This creates a situation in which several countries should feel responsible for taking care of the regions. However, the psychological phenomena of dispersed responsibility may appear—in such a situation, as there is no one nominated entity that takes the lead; all involved parties may feel like they are not responsible, as maybe "someone else will take action". A similar situation occurs when it comes to taking care of the environment on earth, where shared responsibility may decrease individual actions.

Third, polar regions are the most unpopulated regions on the planet. This may create the impression that anthropic pressure is not present there, as direct human influence is not as visible for outside observers (cities and communication infrastructures are, to a lesser extent present). This impression is misleading, as there are many other traces of human presence (whaling stations, trappers' shelters, drift wood, plastic delivered by sea currents, etc (see Węsławski and Kotwicki, 2018), and because many polar areas such as the Kola Peninsula in Russia are heavily industrialized and polluted as well as having several large cities north of the polar circle. Therefore, the initial impression of a lack of human presence in fact is very misleading, but this impression may create in humans the sense of uniqueness of this area and may evoke a special urge to prevent it from further conquest by humans.

Fourth, the spectacular polar landscapes invoke human imagination, operating mostly in reference to sight (the strongest human sense). It seems like this makes it much more convincing to speak to the human imagination based on those icons rooted in the geography and biology of the region. Lastly, the polar regions are indicated as "the only two places" on Earth where a specific polar type of climate can be experienced. This defined uniqueness makes polar regions outstanding.

CHANGING ATTITUDES?

To increase social awareness about anthropogenic threats to polar regions, social attitudes need to be addressed and possibly changed. Attempts to create responsible attitudes towards Arctic were already made especially within the stream of environmental communication practice (Jackson and Surrey, 2005; Leiserowitz and Fernandez, 2008).

Changing attitudes – which this article addresses – is an utterly difficult task that needs to be addressed carefully. Within the social sciences, it has already been proven that changing human attitudes is much more effective if started at an early stage of institutional education (kindergarten or in the first grades of grammar school). In such a situation, defining the attitudes of youth toward polar regions may indicate general attitudes towards environmental protection and how ecological citizenship is experienced in a time of increasing anthropogenic pressure. The attitudes are hidden and not directly observable, but they act to organize or provide direction to actions and behaviors that are observable. Attitudes can also be explained as "predispositions to respond" (Zimbardo and Leippe, 1991). Attitudes vary in direction (either positive or negative), degree (the level of positivity or negativity), and intensity (the amount of commitment with which a position is held).

Attitudes are formed during a long period of informal and formal socialization, based on relations with significant others (depending on the age of the individual, parents, peers, chosen role models). Learning attitudes are a significant part of the socialization process, aiming at educating children and youth (later also to influence adults) and turning them into responsible human beings that can contribute to the society. The culture where individuals live has a strong impact on their attitudes; attitudes that seem normal and acceptable in one culture can be unacceptable or even distasteful in another culture.

Znaniecki and Thomas (1918), in one of the earliest definitions of attitude, proposed to think of attitude as a mental state of readiness, organized through experience, using a directive influence upon the individual's response to all objects and situations with which it is related. Later, Zimbardo and Leippe (1991) defined attitude as an evaluative character toward some object based upon cognitions, affective reactions, behavioral intentions, and past behaviors.

Katz (1960), in his classical research, has recognized the importance of the study of attitudes and noted that there are four roles denoted for attitudes. First, attitudes allow to organize an individual's daily activities and responses to events that occur; Second, attitudes help in achieving goals and in avoiding punishment; Third, attitudes contribute to the enrichment of self-esteem; and fourth, attitudes, and values allow for the expressing of emotions and behaviors. In an obvious way attitudes affect an individual's performance and behavior toward other humans and the general surrounding environment.

Pickens (2005) linked the notion of attitude with perception, the process in which an individual interprets and organizes feelings to create a meaningful experience of the world. In other words, the person interprets the stimuli based on previous experience and socialization.

Lippmann (1946) proposed a concept of attitudes concerned with how indirectly people know the environment in which they live and how they believe it to be a true picture. He claims that, for individuals, the real environment is too overwhelming to handle cognitively, and this forces humans to reconstruct reality in the form of simpler representations (stereotypical thinking). Based on these stereotypical representations, attitudes are formed. To maintain cognitive balance, humans tend to defend attitudes that are already formed. Lippmann (1946) also defined the concept of “images in human heads” (stereotypes) that nurture certain attitudes, support them, and make people act in certain ways.

Psychologically and sociologically, attitude is defined as a “coherent structure consisting of three components: affects, behaviors and cognition”. This definition is widely accepted by social sciences, as it can be operationalized easily; however, various paradigms underline the importance of different components: behaviorism emphasizes behavior as a key component in attitudes, psychoanalytical approaches focus on affects, and cognitive approaches refer mostly to opinions. Therefore, a behavioral approach focuses on the application of either aversive or positive stimuli, which is a base for the process of conditioning that leads to avoiding stimuli or searching for it. Psychoanalytic theories apply an approach in which attitudes may be treated as a self-defense mechanism aimed at protection of the self. Changing attitudes is possible by identifying internal conflicts in personality and exposing them. In this process, subconscious conflict moves into the conscious level, which allows dealing with the problem in an effective way. Lastly, cognitive approaches aim at changing attitudes by providing specific types of information, which at first may create cognitive dissonance and later will cause a search for change of attitude to maintain cognitive balance. (Mosler, 2001 pp.569–577, Patchen, 2006 p.2–5).

Affect, behavior, and cognition are three interrelated components of attitudes that stay in dynamic interdependent relations (Eagly and Chaiken, 1993; Philipchalk, 1995). Connections among those three elements are significant, and a change in one of them directly affects the others. According to Philipchalk (1995), the study of attitudes is critical, not only because it results in discoveries about how people feel, think, and behave, but also because those discoveries allow them to shape attitudes. Only very rarely can attitudes be identified as isolated ones. In most cases, they are interconnected with other attitudes; therefore, changing one of them may cause chain reaction-provoking change in other attitudes.

Recent research distinguishes between explicit and implicit attitudes (Scior and Werner, 2015). The concept of explicit attitudes means that the respondents are often asked by using questionnaires in which they indicate what they think, feel, or intend to do. However, the concept of implicit attitudes means that the respondents are not always aware of their attitudes; therefore, more sophisticated methods have to be used. Following the concept of implicit attitudes, various ways originating from projective methods are used (for example, displaying a large number of words from which subjects have to choose the right words expressing their attitudes in the most adequate ways). Scior and Werner (2015) summarized that implicit attitude tests provide a better indicator of individual behaviors.

In sociology, researching attitudes is an important stream of research, as identifying current attitudes allows the application of practical changes aimed at finding solutions for social problems. Changing attitudes is a challenging but possible task, requiring an extended theoretical background. Depending on the paradigm applied, various strategies are proposed. If a behavioral-cognitive paradigm is to be followed, to cause change, one needs to influence those two elements (behavior and opinions). Pickens (2005) claims that to change attitudes, it is recommended to contact the cognitive and emotional components of the attitude. When an individual has negative attitudes toward a particular topic, it is possible to change attitude by bringing new, relevant information on the subject.

Ajzen and Fishbein (1980) in their theory of reasoned action, advocated the ABC model (Affection-Behaviour-Cognition) and concentrated on efforts to examine the relationships between attitudes. Ajzen and Fishbein (1980) interpret attitude as a tendency to react consistently to a given stimulus, as sympathetic, or not sympathetic, and attitude is currently a mixture of prominence beliefs about the output behavior, with the individual evaluation about the outcome behavior. All this, can be reflected in a specific measurable scale. Ajzen and Fishbein (1980) argued that it is important to understand the behavior before it can be changed, as motivation is a key component in influencing behaviors.

The theory of reasoned action reflects a social psychological approach to understanding and predicting behavior (Ajzen and Fishbein, 1980). Human behavior is reviled based on existing intentions, which indicate the degree of effort that people are willing to invest to do something. The more severe the intent, the more likely it is to occur. One can better understand the relationship between the elements in attitudes if one accepts the assumption that humans are rational and that they take into account the implications from their actions. Subjective norms, is a concept that discusses the impact of the social environment on behavior and is used as a basic component in the theory. The term describes the normative level of stress that is perceived by the individual, whether to perform or not perform a certain action. The individual tends to perform the behavior when he believes that “significant others” think he should do it. “Significant others” can be (as mentioned before) parents, spouses, close friends, co-workers, managers, and so on (Ajzen and Fishbein, 1980; Ajzen, 1991).

Ajzen (1991) claimed that as long as an individual believes he hathey have the resources and opportunities, that will encounter the least number of obstacles, the more they can control his behavior. Ajzen (1991) adds that the observed behavioral control concept is suitable to Bandura theory (Bandura, 1977), for example, the observed self-efficacy (perceived self-efficacy) when referring to the individual’s judgment of how well the required action to deal with the situation can be performed. Self-assessment of future success depends on the experience of the subjective perception of difficulty in meeting a new challenge.

Changing attitudes is a long process that requires effort and determination. Educators should understand that the process is not easy and must develop realistic expectations about time and change. Further, the processes of socialization and the attitudes that are created are accompanied by beliefs and values and are affected by various factors such as family, religion, culture, and socio-economic factors (Pickens, 2005). Individual characteristics are also major factors that can affect attitude change. Thus, to predict the chances of an attitude change, it is important to examine not only the characteristics of the attitude, but also the attributes of the attitude's owner (Carmil and Breznitz, 1991).

Chaiklin (2011) studied the relationship between attitudes, behavior, and social practice and noted that attitudes are important in creating general societal approaches to important social issues and challenges. Voas (2014) points out that social norms are created in a way that the individual appreciates and relates to the subject as good, or bad. He claims that until the last century, psychologists were the ones who had studied the issue of attitudes, and sociologists have neglected this issue, even though they referred to the gap between what the individual says vs. what he does. Therefore, it is important to examine the issue of attitudes as normative statements about the social order rather than the individual's subjective feelings, likes, or does not like.

Voas (2014) argued that today, the sociology of attitudes is underdeveloped. He attributed great importance to sociological attitudes, positing that since humans base actions on attitudes, we think about society and the rights and obligations of the people. The attitude judgment is personal and expresses values. Understanding the nature of attitudes from a sociological perspective helps to decide what to measure and how important it is to examine and clarify beliefs, preferences, and the relationship between values and attitudes. Understanding the sociological aspects of attitudes also helps clarify the status of some key concepts, such as concern and responsibility.

Extensive research on theoretical approaches to changing attitudes has already been carried out and has also been applied in the everyday social practice of changing attitudes. Moreover, theoretical tools were successfully employed in the process of modifying precise types of attitudes—those toward nature, the environment, and their protection. There are many examples of the influence of human attitudes on environment. Anable et al. (2006) provided an extensive review of relations between public attitudes to climate change and everyday human habits—in this case, transport, and commuting behaviors. They emphasized the need to raise public awareness of this link. They claimed, however, that in order to create effective change, many levels of action need to be taken: at the objective and subjective and at the individual and collective levels. The authors also claimed that the psychological process of changing attitudes may be very slow: behavior changes first, and only later is there a change in attitude. They also underline the need to apply deliberative methodologies that deviate from traditional 'top-down' methods of information provision: two-way communication and learning by doing.

Frantzen and Vogl (2013) provided a country ranking of public environmental concerns based on an analysis of data collected by the International Social Survey Programme from 33 countries over the past 2 decades. Their data highlighted the fact that environmental concerns have recently decreased in almost all nations. They observed clear connection between the wealth of the country and a higher level of concern about environment. This observation corresponds with the classical concept of Abraham Maslow—the pyramid of needs. Needs of higher level can be fulfilled only after basic physiological needs are satisfied.

Patchen (2006) offered sociological insight into changing public attitudes and followed a classical sociological approach by analyzing demographic data and linking results with possible ways of creating change in attitudes. He stressed that, to create effective change in attitudes, one needs to personalize information—this allows identification and connection between personal narrative, information, and the effects of behavior. He emphasized the role of both individual actions and collective efforts inspired by organizations. Lachapelle et al. (2012) added to this the need for coherent political decisions made by policymakers at various levels of societal organizations.

There are also very practical examples of how to influence a change in attitudes towards climate change by using educational actions. Sousa et al. (2016) described an educational experiment in which a pond habitat was used to confront students with biodiversity. By using a quantitative research methodology based on a Likert scale commonly used in sociology, they proved that a project increased students' knowledge and attitudes towards biodiversity. This is just one of several examples of changing public attitudes and increasing awareness of biodiversity, climate change, and wide environmental protection.

INCREASING SOCIAL AWARENESS OF ENVIRONMENTAL PROTECTION

All of the above-mentioned processes of anthropic pressure cause increasing threats to nature and the protection of the environment. The polar regions are very distinctive and unique and are also symbolic. Increasing social awareness about the need for protection of these regions has immense meaning in the general approach of humans toward nature and the sustainable management of social resources. Therefore, educating the public seems to be of crucial importance. Many authors indicate that there is a growing need to extend links between science and society, as this may increase consciousness about negative human influences on the environment (see Barbour, 2008; Harrison et al., 2009). An increasing level of education may cause changes in attitudes toward both polar regions and the environment in general. However, a Hamilton (2008) indicated, possessing a high level of knowledge does not always result in increasing concern about the environment. It seems that an emotional component needs to be added, as this one can be treated according to psychological and psychoanalytic approaches as a factor that causes the change (Firdaus et al., 2016).

Today, public opinion is confronted with opposing narratives in an increasingly polarized media landscape. On one hand, there is a promotion of the extended fear of nature (underlining all types of threats that potentially could be related to nature-diseases, accidents, dangers). On the other hand, the need for connection with nature-biophilia is being exposed as a natural human desire that needs to be fulfilled to develop properly. Facing the Anthropocene in the 21st century, social sciences are obliged to propose meaningful effective tools that may change human attitudes towards the environment. Development of social awareness and consciousness about anthropic pressure in the Anthropocene is our duty and obligation. Ensuring effective communication with the public can be achieved if there is a strong link between science and institutions representing public opinions (Harrison et al., 2009). Providing direct access to the scientific results of research can fill the gap and may provide the emotional component needed to effectively change attitudes.

SUGGESTIONS FOR EMPIRICAL RESEARCH

It seems quite obvious that there is a burning need for empirical research of attitudes toward polar regions to create effective programs of protecting them. Following the context described above, we argue that it seems as though it could be effective to apply a cognitive-behavioral approach fostering modification of attitudes by providing information on the polar regions. We assume as well that certain types of behaviors (like traveling to polar regions) cause emotional experiences that eventually strengthen attitude; therefore, we apply the hypothetical assumption that experiencing emotions connected with the subject may change attitudes towards polar regions. For instance, future research could explore whether respondents' attitudes toward polar regions are connected with attitudes toward the protection of the environment in general. Using the theoretical background presented above, we thus suggest the following: First, social attitudes toward polar regions in selected categories of respondents (especially young people as those who will soon become decision makers) should be identified. Secondly, an analysis of whether identified attitudes can be treated as reflections of more general attitudes toward the responsibility for environmental protection and climate change must be conducted. Finally, methods aimed at increasing awareness of polar regions and responsibility for environmental protection, following a cognitive-behavioral approach strengthened by an emotional component (presentation of scientific research), can be proposed.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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