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RESEARCH ARTICLE

The importance of discourse when discussing microplastic pollution with oyster stakeholders in Massachusetts, USA

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Abstract Oysters have socioeconomic and environmental importance globally and are currently threatened by microplastic pollution. Whether solutions (e.g., laws, policies, or best management practices) are needed to protect oysters from microplastic pollution is still in question given the complexity of the issue and the multitude of stakeholders involved. Minimal research has been done to examine the public's view of the microplastic problem and, separately, few economic studies have examined non-monetary values for oysters. Here, we employed a discourse-based method (deliberative multicriteria evaluation methodology) to engage with oyster-relevant stakeholders in Massachusetts, USA, to evaluate how the stakeholders discussed and interacted with each other on the topic of 'microplastics polluting oyster habitats' using hypothetical scenarios. Our qualitative analysis indicated that participants discussed human welfare and non-human welfare aspects of oysters when considering what is threatened by microplastic pollution in oyster habitats. In all the workshops, an important theme emerged which is the role of oysters in supporting services (e.g., the concept that microplastic filtration or ingestion by oysters might impact the oysters' role as eco-engineers). Decision-making is not a linear process, especially when complex pollutants (e.g., microplastics) are involved. Here, we learned that both environmental and social data are needed for the oyster stakeholders to make decisions, and discussion among stakeholders can highlight gaps in scientific knowledge. The results were then used to inform the development of a decision-making process for evaluating complex environmental issues, like microplastic pollution.

Keywords Applied thematic analysis · Deliberative valuation · Microplastics · Oysters · Stakeholder engagement · Trade-off weights

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13280-023-01870-z.

INTRODUCTION

Plastic pollution occurs globally and, like climate change, it reflects our ability to affect the environment on a global scale (Persson et al. 2022). Plastic is the most abundant form of marine debris, and with its tendency to fragment into micro- (< 5 mm in one dimension) and nano-sized (< 1 µm in one dimension) particles, it affects marine life and threatens human life (Hale et al. 2020; Landrigan et al. 2020). The presence of microplastics in the environment raises concerns for the environment at large, particularly for species that filter large volumes of water, such as oysters (Kinjo et al. 2019). Globally, 94.4% of oysters have microplastics present in them, with higher concentrations occurring in wild versus aquaculture oysters (Wootton et al. 2022). The frequent occurrence of microplastics in oysters has potentially important implications for oysters, the ecosystem services derived from oysters, and for humans that fish and feed on the oysters.

Serving as an ecosystem engineer, oysters provide benefits to both the environment and to humans (Pollack et al. 2011; Depiper et al. 2017; Kecinski et al. 2018). As suspension feeders, oysters aid in regulating water quality (Beck et al. 2011; Michaelis et al. 2020). Oysters filter the water, which reduces the presence of algae and other suspended solids in the water (Beck et al. 2011; zu Ermgassen et al. 2013; Kecinski et al. 2018; Michaelis et al. 2020).

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Oysters create reef-like structures that provide habitats for other species (Beck et al. 2011; Michaelis et al. 2020). These 'oyster reefs' provide foraging opportunities for larger fish and marine mammals as well as support nursery grounds for fish (Beck et al. 2011; Depiper et al. 2017; Michaelis et al. 2020). In terms of human welfare, oysters provide employment and income, food, flood mitigation and cultural identity (Baillie and Grabowski 2019; Michaelis et al. 2020).

Globally, mollusks are the second largest farmed seafood, with oysters being the dominant mollusk grown (Botta et al. 2020). In 2020, oyster landings in the US were valued at nearly $187.2 million (National Marine Fisheries Service (NMFS) 2020). The eastern oyster, found throughout the northeast coast and Gulf of Mexico, historically accounts for 75% of the oyster landings and is recognized for its direct fisheries value (Baillie and Grabowski 2019; Hartmann et al. 2019). Further, in Massachusetts, USA, shellfish aquaculture resulted in over 900 jobs with $45.5M generated in the MA economy in a 2015 study (Augusto and Holmes 2015). The oysters in Massachusetts (MA) are currently threatened by pollution and disease. The US Census Bureau ranked MA fifth in highest human population density in the United States (Kennedy et al. 2020). Because of this high population density, the nearshore waters of MA are especially susceptible to degraded water quality from sewage contamination and increased microplastic loads (Kennedy et al. 2020; Tobin 2021).

Whereas microplastics are a global concern, minimal research has been done to examine stakeholders' views, on the plastic problem (Charitou et al. 2021; Forleo and Romagnoli 2021). Yet, stakeholders play an important role in combating plastic pollution (Forleo and Romagnoli 2021), influencing policy formation (Clausen et al. 2020) and in plastic risk perception (Syberg et al. 2018). Further, there is much debate about the need to regulate (micro)plastics (Burton 2017; Backhaus and Wagner 2020; Völker et al. 2020). Some researchers rely on future impacts associated with (micro)plastics (e.g., if plastic production continues business-as-usual) (Jambeck et al. 2015). Others argue that impacts seen in the scientific literature at environmentally relevant concentrations are so minimal, that the public outcry against microplastics is not warranted (Burton 2017; Rist et al. 2018; Provencher et al. 2020; Völker et al. 2020). These contrary opinions illustrate the complexity of plastic pollution and the need for a transdisciplinary approach involving multiple stakeholder groups.

To assess stakeholder perception and values, recent literature has examined discourse-based methods (e.g., deliberative multicriteria method, deliberative monetary valuation) as an alternative to traditional valuation techniques (Mavrommati et al. 2017; Bartkowski and Lienhoop 2019). As such, discourse-based methods rely on the theories of deliberative democracy that argue for more active participation in decision-making and emphasize the collective meanings, significance, and value derived from ecosystems (Bunse et al. 2015; Kenter et al. 2016; Bartkowski and Lienhoop 2019). These methods provide opportunities for interactions among stakeholders and between stakeholders and experts; when these interactions are effective, then social learning is cultivated, and the willingness to support conservation policies may increase (Mavrommati et al. 2021).

Deliberative valuation (DV) allows for the value of nature to be communicated clearly (Bartkowski and Lienhoop 2019). The deliberative multicriteria evaluation (DMCE) method, an extension of DV, combines the advantages of multicriteria decision analysis with local knowledge building through deliberation (Proctor and Drechsler 2006; Mavrommati et al. 2017). The DMCE methodology allows for environmental attributes that have different measurement units and/or cannot be quantified in monetary units to be compared against each other in discussions by relevant stakeholders (Mavrommati et al. 2017). In doing this, stakeholders participate in a co-learning exercise where they can clarify and homogenize values among the various participants (Voinov and Bousquet 2010). Much of it relies on the ability of stakeholders to communicate and exchange information and knowledge (Voinov and Bousquet 2010).

Qualitative and quantitative data can be extracted from DMCE experiments, allowing researchers to trace the reasoning behind participant and group choices using techniques such as content analysis, thematic analysis, and social network analysis (Almalki 2016; Mavrommati et al. 2021). Applied thematic analysis (ATA), is a type of inductive analysis of qualitative data that can involve a multitude of analytic techniques (Guest et al. 2012), whereas social network analysis investigates the dynamics of influence through group deliberation (Freeman 1948; Otte and Rousseau 2002; Prell et al. 2009; Marin and Wellman 2015).

The utilization of the DMCE method results in an extra layer of information which may allow researchers and policy makers to better understand the tipping point of people's preferences to inform policy. Thus, involving stakeholders in the decision-making process is a useful tool where unpopular decisions are hard to implement (Voinov and Bousquet 2010). The DMCE method has been employed in multiple settings for problem solving in environmental resource management (Proctor and Drechsler 2006; Garmendia and Gamboa 2012; Karjalainen et al. 2013; Mavrommati et al. 2017). Here, we provide a case study for utilizing the DMCE methodology to discuss a complex, environmental issue (microplastics polluting oyster habitats) with a diverse set of oyster related stakeholders (e.g., academic, government, non-profit, and industry sectors). We organized three virtual

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workshops with 29 stakeholders. We used decision theory to select six indicators that describe the various ways that oysters contribute to human welfare and environmental ecosystem services and developed the workshop choice tasks with those indicators represented as 'scenarios.' Stakeholders had to perform the choice task keeping in mind the potential threats from microplastic pollution (a 'microplastics ocean'). The resulting data were then used to (1) evaluate how stakeholders discussed and interacted with each other on the topic of microplastics polluting oyster habitats and (2) create a decision-making process for evaluating complex, transdisciplinary problems like microplastic pollution.

MATERIALS AND METHODS

Study domain

The focus of this research is MA, USA, where uses of oysters include oysters produced for aquaculture, fished for recreational fishing, and grown for environmental purposes (water clarity improvements and flood mitigation). These oysters are also currently threatened by pollution and disease. Because of high human population density, the nearshore waters of MA are susceptible to degraded water quality (Browne et al. 2011; Kennedy et al. 2020) and high microplastic concentrations (Browne et al. 2011; Kennedy et al. 2020; Tobin 2021).

The deliberative multicriteria evaluation (DMCE) methodology

Stakeholder recruitment

Figure 1 illustrates the steps of the DMCE method. Stakeholders were contacted using the snowball sampling technique (Herweyers et al. 2020). Of the 93 stakeholders contacted, 29 participated. The participants represented government, academia, non-governmental organizations, and industry (hatchery and business owners) (Table 1). Representatives from the general public were approached but were unable to attend. Initially, stakeholders were each assigned to one of the three dates by the workshop organizers so that an equal representation of stakeholder categories was present on each date. However, due to the effects of COVID-19 on the workshop implementation (Tobin et al. 2020), equal representation was not always possible.

Indicator selection

We selected socio-, economic, and environmental indicators that relate to oysters (Table 2). The indicators chosen represent various end-points that pertain to the human welfare benefits of oysters (e.g., employment, income, cultural identity) and ecosystem services (e.g., shoreline protection, water clarity) that could be threatened by microplastic pollution (Smith et al. 2013; OECD 2016). Governmental and non-governmental reports were used to derive current numerical values (proxy indicators) for each of the indicators evaluated. From the current values, assumptions were made to obtain best and worst values. Due to data availability, the list is not all-encompassing; rather, it is meant to highlight some, but not all, uses of oysters in the study area. We used the specific indicators to develop the choice task for the workshops described in "Description of choice task section" section.

Table 1 Stakeholder participation per workshop

Stakeholder category	Workshop 1	Workshop 2	Workshop 3
Academia	3	2	1
Government	1	7	4
Non-Governmental Organization (NGO)	3	2	2
Industry	1	2	1
Total	8	13	8

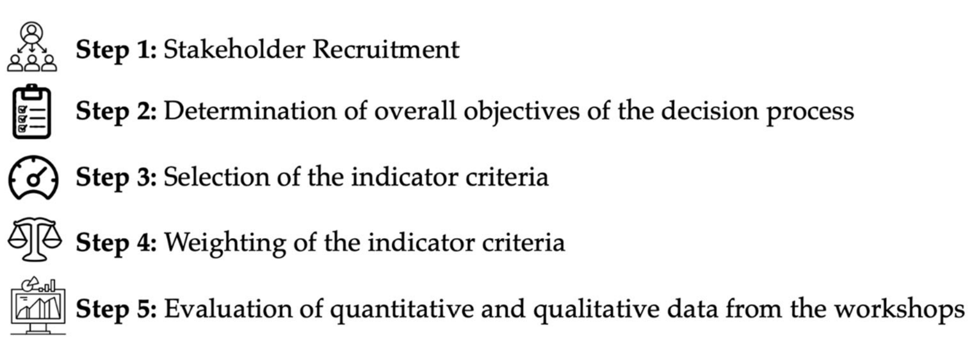

Fig. 1 Steps of the deliberative multicriteria evaluation methodology (modified from Tobin et al. 2020)

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Description of choice task section

Workshop structure

Prior to the workshop (Phase I), participants were introduced to the socio-, economic, and environmental indicators as well as the concepts of microplastics and uses of oysters via pre-recorded videos from the host and experts. They were also provided with the necessary links (for Zoom and GoogleSlides) and instructions for accessing the workshop virtually. During the workshop (Phase II), participants were introduced to the deliberative process and the nature of the valuation task. Then participants performed the choice task individually and collectively described by Tobin et al. (2020). These tasks involved the prioritization (or, ranking) of each of the scenarios (Fig. 2). Participants were asked to consider the scenarios within a 'microplastics ocean' based on the information they were provided by the expert presentations on the presence and impacts of microplastics in oyster habitats. Here, a 'microplastics ocean' is defined as a world in which microplastics are present throughout the water at all times. The experts were also available to answer questions in real-time throughout the workshop. A professional facilitator managed the discussion to keep the participants on task and to encourage full group participation. After the workshop, we asked participants to perform the choice task again and complete a post-survey (Phase III).

Description of choice task

Utilizing the swing weighting method, each of the indicators were set at their worst level (Keeney and Raiffa 1993; Gregory et al. 2012) for the 'Worst of all Indicators' scenario (Table 2). Relative to this, other hypothetical states, in which one indicator at a time was 'swung' to its best level, were represented by six other scenarios (Fig. 2) (Mavrommati et al. 2017). By default, 'Worst of all Indicators' scenario occupied the lowest rank with a value of zero. Throughout each workshop, the other scenarios were assigned values between 1 (least desirable) and 100 (most desirable). Stakeholders completed this task individually twice by completing an online form at the beginning of the workshop and one-week post-participation date. This task was also completed collectively using an interactive digital visualization that depicted the scenarios as cards placed on a line (referred to as a meter stick with stakeholders) with the values 0 to 100 on it. After the group finished an icebreaker activity, the stakeholders were tasked to decide how to assign each scenario its weighted rank. During this task, participants discussed their thoughts and opinions on the rankings in real-time. Additionally, participants were encouraged, but not

Table 2 Definition of indicators used to represent the socio-, economic, and environmental uses of oysters in MA

Domain	Indicator name	Units	Current value	Best level	Worst level	References
Basic Human Needs	Permit Issuance	# of permits	1750	2275	1225	Kennedy et al. (2020)
Economic Needs	Sector Income	$$	20 000 000	30 000 000	8 500 000	Department of Fish and Game-Massachusetts Division of Marine Fisheries 2015 Annual Report, (2015, 2016, 2017, 2018) and Massachusetts Division of Marine Fisheries 2014 Annual Report (2014)
Environmental Needs	Shoreline Protection	Feet per year	0	5.5	− 10.5	Haney et al. (2015) and Thieler et al. (2013)
	Water Clarity	%	35	50	25	Environmental Monitoring Data from Boston Harbor and Tributary Rivers (n.d.)
Subjective Human Well Being	Food Culture	# of retail seafood dealer permit	950	1235	665	Department of Fish and Game-Massachusetts Division of Marine Fisheries 2015 Annual Report (2015, 2016, 2017, 2018)), Massachusetts Division of Marine Fisheries 2011 Annual Report (2011, 2012, 2013, 2014)
	Recreational Fishing	# of recreational fishing permits	500	> 1000	< 50	Kennedy et al. (2020)

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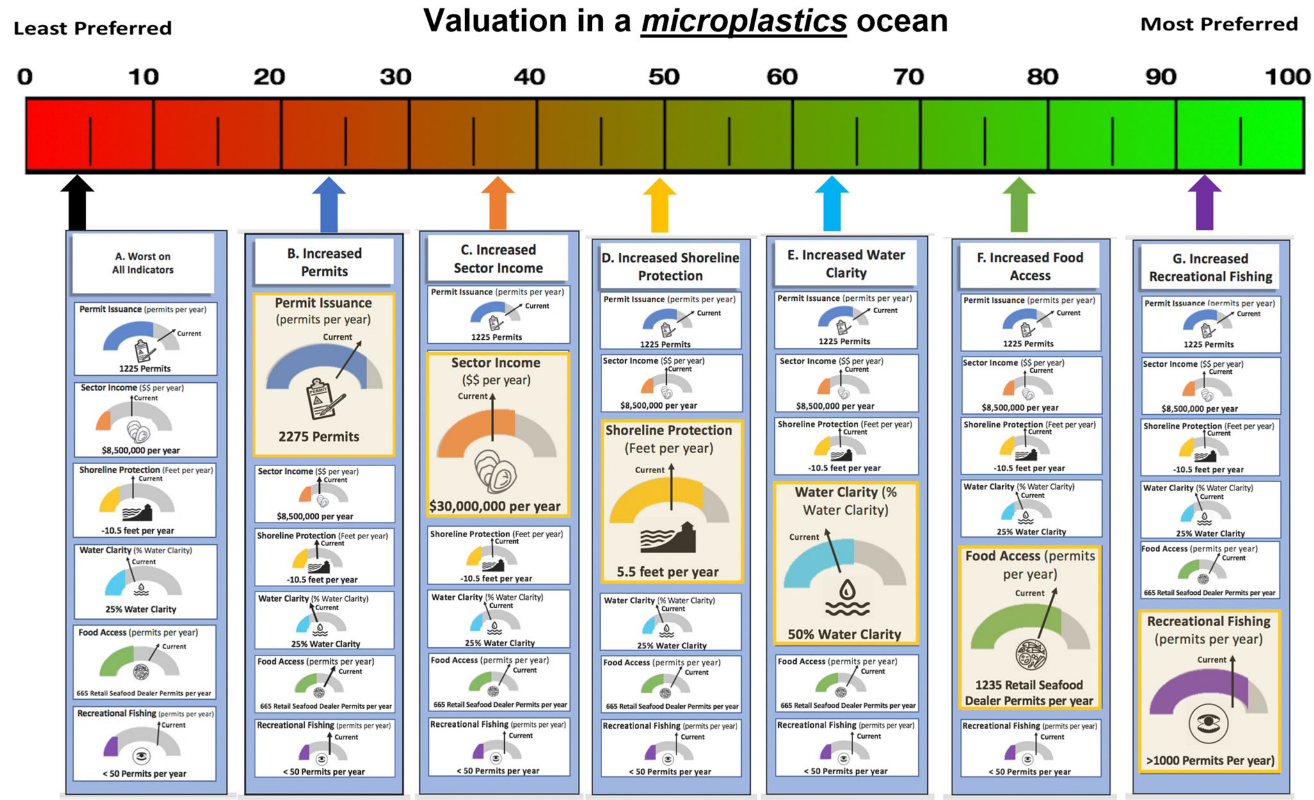

Fig. 2 Examples of the cards used in the assessment task. In these examples, each card represents (1) indicator at its 'Best' level, with the remaining indicators at their 'worst' level. Participants were asked to move the individual cards to the appropriate number on the meter stick based on their rankings

required, to reach a consensus as a group in terms of the rankings of the scenarios. Since this group task is a dynamic process, a professional facilitator was used to keep the participants on task as well as to remind them to reach consensus, if possible.

Evaluation of quantitative and qualitative data from the workshops

The weighted rankings in all three choice tasks were aggregated using the swing weighting method (Mustajoki et al. 2001) resulting in trade-off weights for each participant and each group. This provided the foundation for quantitative analysis.

Further, we conducted social network analysis plus an ATA (Guest et al. 2012; Froehlich et al. 2020). Upon consent from the participants, the three workshops were audio recorded and then transcribed by a third-party service. The transcripts were corrected as necessary by the researchers. This included removing all personal identifiers for the participants and removing all signifiers in the transcripts that were not speech from participants. We examined the transcripts by (1) exploring group dynamics and the flow of influence through the agreement network analysis; (2) identifying themes and subthemes of discussion; and (3) determining the frequency of plastic-related and all words in the word count analysis. All analyses were completed and verified by two independent coders. The analysis required the software Microsoft Word, Microsoft Excel, as well as R and RStudio. For each part, the qualitative data were analyzed from a stakeholder grouping perspective (Academia, Industry, Government, Not-for-profit).

The transcripts were coded for instances where any participant outwardly agreed, or implicitly agreed, with any other participant. This was, in most cases, identified when a participant specifically referenced another participant. All instances were recorded by recording the 'target' (participant agreeing) and the 'source' (participant agreed with) for each observation. These data were then visualized as a multi-attribute-directed network analysis.

The work here used ATA to analyze themes and word counts. For the theme analysis, coders independently read through the transcripts, highlighting any participant dialogue that brought up new or recurring topics, or ideas used to defend a preference (Mavrommati et al. 2021). These topics were clustered into increasingly broad categories. Then, coders came together to review their ideas and collaborated on a final list of themes and subthemes. This was completed for three areas: (1) themes, (2) science and

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policy considerations, and (3) procedural considerations. Once defined, the coders then independently re-reviewed the transcripts to code the text for each subconsideration in each of the three areas. With that analysis, we were able to calculate a percent of occurrences per consideration per stakeholder category to begin to understand how these were discussed across and within stakeholder groupings.

For the word count analysis, transcripts were manually and independently aggregated for (a) general word count and (b) occurrences of words used to represent the theme "plastic" (e.g., "plastic," "fiber," "filament," and "particles"). A 1-min buffer was implemented to omit keywords that occur within the same idea from a single participant. Redundant words and phrases were removed. The word count was then obtained utilizing the word count feature in Microsoft Word.

RESULTS

Summary of trade-off weights and the deliberative process

Participants in all three workshops were able to complete the task (Table S1) and reach consensus. Figure 3 compares the group value (labeled as 'consensus') to the weights of each scenario per participant. All stakeholder categories had a higher pre-deliberation score compared to consensus for Scenario B (Permits Issued). This suggests that Scenario B (Permits Issued) was highly valued by individuals prior to discussions but deliberations caused the value to decrease. Interestingly, the individual values for Scenario B (Permits Issued) increased again in post-deliberation surveys when compared to the consensus value for all groups except NGOs. This suggests that all other participants maintained their initial considerations even after deliberation.

For Scenario E (Water Clarity), all stakeholder groups except Academia had pre-deliberation trade-off weights less than that of the consensus value. However, all groups had post-deliberation weights greater than shared. This suggests this scenario continued to gain importance even after the workshop's completion.

The 'Industry' stakeholder category had the same individual pre-deliberation value compared with the shared for Scenario F (Food Access). This indicates that this group was able to convey the importance of this particular scenario to other groups during deliberation so much so that the NGO and Academic categories valued this scenario even greater than the consensus in the post-deliberation survey. Interestingly, the sample size for this group was much lower than the other stakeholder categories (Table S1). However, industry's value decreased in their post-deliberation score.

The trade-off weights were reasonably similar across scenarios (Tables S2 and S3). Scenario D (Shoreline Protection) and E (Water Clarity) had the highest pre-deliberation and post-deliberation trade-off weights. The means did not change significantly when comparing the other scenarios for pre-deliberation and post-deliberation.

The pre- and post-deliberation trade-off weights were further compared by scenario per workshop. Significance was only found for Scenarios E (Water Clarity) and G (Recreational Fishing) for Workshop 1 ($p < 0.05$; Wilcox Test) indicating that those two scenarios were significantly impacted by deliberation. No significance was found for all other scenarios for each workshop. Data for all workshops were then combined to determine whether there were significant differences between pre- and post-deliberation trade-off weights per scenario. Post-deliberation trade-off weights for Scenarios D (Shoreline Protection), E (Water Clarity), F (Food Access), and G (Recreational Fishing) were significantly different from pre-deliberation (p-value < 0.05; Kruskal–Wallis).

Summary of procedural considerations

The trade-off weights were the quantitative measure to assure that participants completed the choice task. Given that the DMCE methodology was employed in a non-traditional, virtual format, we wanted to capture how participants engaged with the DMCE methodology based on the instructions provided throughout the workshop. Specifically, we wanted to confirm that participants understood the choice tasks that they had to perform. Even though minimal significance was found with the trade-off weights, there were interesting results when analyzing the qualitative data. 'Procedural considerations' is when a participant considers the underlying process regarding their involvement in the workshop (external threats, locational framing, clarifying instructions, and linking scenarios) and brings that consideration into the discussion. Table 3 summarizes the procedural considerations defined in this analysis.

The instructions for the choice task required participants to complete the exercise within the study domain of MA. Thus, if a participant ranked shoreline erosion high because of its importance in the southern states, the facilitator would remind them that we are only working within the MA context. At times, that would influence a participant's ranking.

Participants were asked to consider oyster resources in MA in a 'microplastics world.' In other words, participants were asked to make their rankings under the assumption that the external threat of microplastics is present in MA coastal waters. Several participants also considered other outside threats that were influencing their decisions. Topics such as climate change and COVID-19 were mentioned by multiple stakeholders (Table S4) as influencing their decisions. During one of the

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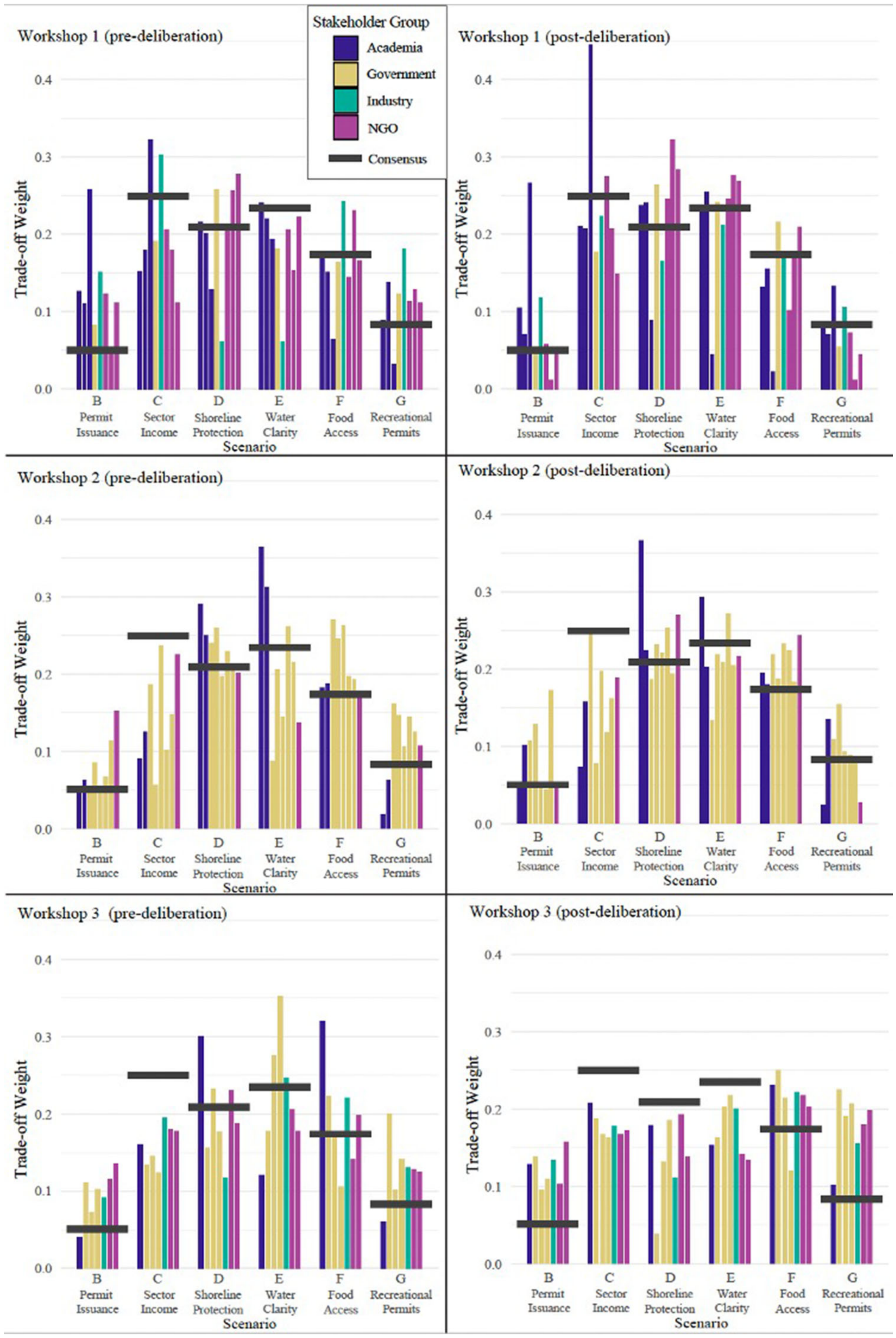

Fig. 3 Trade-off weights for each of the indicators per group per workshop compared to the shared consensus value. Each vertical bar represents an individual participant. The horizontal bar is the shared consensus value per indicator per group

workshops, a participant said "…I was thinking pre-COVID, but COVID's factoring into our lives right now and it's devastated our industry, both coasts, all coasts…". This suggests that their valuation was taking those topics into consideration.

One of the unique aspects of the DMCE methodology is the ability of participants to ask procedural questions throughout the workshops and for hosts to offer clarifying instructions in real-time. For example, one participant said "…it sounds like what you're really looking to understand is if microplastic pollution were to change in intensity or volume, and that were successfully conveyed, scientifically and in a messaging way and that kind of thing, what would be

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Table 3 Definitions of Procedural Considerations

Procedural Considerations—When a person considers (WAPC) the underlying process regarding their involvement in the workshops	
External Threats	WAPC things acting on the system that is outside of their control, other than microplastics (e.g., climate change, COVID)
Locational Framing	When a participant specifies the location they are viewing their perspective from
Clarifying Instructions	When a participant (1) asks for an explanation to make instructions clearer (includes fact checking with experts) or (2) comments on their own misunderstanding of the workshop's assessment task
Linking Scenarios	WAPC the influence a certain scenario has on another scenario

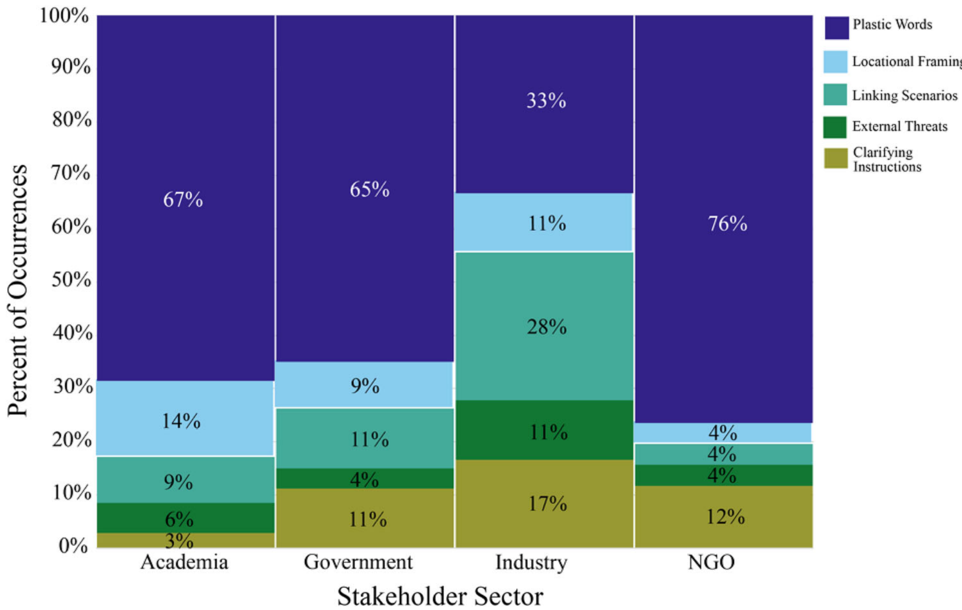

Fig. 4 Percent of occurrences of Procedural Considerations for each stakeholder category

affected the most" (Table S4). The frequency of this occurring across all workshops was minimal (3–15%) but apparent (Fig. 4). This suggests that the instructions provided at the start of the workshop were clear and minimal time was needed throughout deliberation to offer any clarifiers.

Participants were asked to view each scenario in a vacuum. Meaning, the increase in one would not automatically increase another. Even with those explicit instructions, participants struggled with not linking the scenarios (Fig. 4; Table S4). Additionally, the frequency of use of plastic words was captured to determine whether participants considered plastic in their discussions. Figure 4 shows that each stakeholder category did, in fact, reference 'plastics' throughout deliberation (67% Academia; 65% Government; 33% Industry; and 76% NGO). These data in tandem with the quantitative data illustrate that participants were able to complete the task required, reach consensus, and consider 'microplastics' in their deliberations.

Knowledge sharing

Figure 5 illustrates the agreement analysis by workshop and all workshops combined (bottom right of Fig. 5). When an arrow points from node A to node B, this means that A agrees with B. Each node in this plot represents a participant from a particular stakeholder sector, except in the case of all workshops combined when each node represents the aggregation of all stakeholders for a particular sector. The edges between them represent the agreements between participants of each sector. The width of the arrow's line represents the frequency of agreement between the two participants. The greater frequencies of agreement (indicated by a thicker arrow) were between government and academic stakeholders (in both directions) and between government and NGO stakeholders with government agreeing with NGOs frequently.

When looking at the dynamics of individual workshops, the silos begin to appear. These silos appear to be participant

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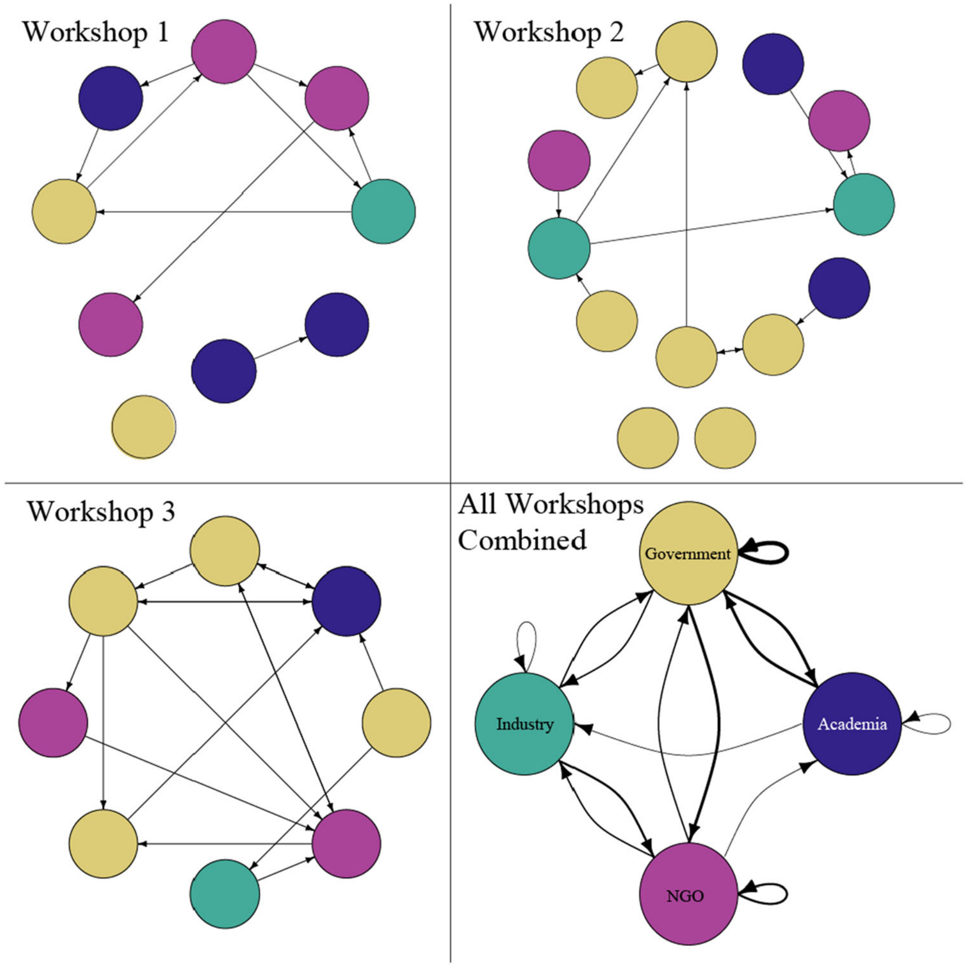

Fig. 5 Agreement Network of Stakeholders for workshops (1–3) and overall (bottom right). The destination of the arrow indicates the sector that is agreed with by the source (base of the arrow). The thickness of the line indicates the frequency of occurrence

specific, not stakeholder category specific. Workshops 1 and 2 have nodes that are not connected to other nodes. This indicates that there was no outwardly explicit agreement between those participants and others in the group. In both instances, those participants are from the government stakeholder category. It is important to note, however, that this agreement analysis only accounts for outwardly implied agreement; it does not factor in if a participant silently agreed with another during deliberation or when finalizing the group's rankings. Thus, we cannot imply that the three government stakeholders that are not connected to other participants did not agree with any other participants. Even though we video recorded the discussions, not everyone had their camera on so we cannot explore this further from our video data. Additionally, workshop 2 had almost 2 × the number of participants compared to workshop 1 (14 compared to 8, respectively) (Table 1).

Workshop 3 had the most dynamic agreement interactions compared to workshops 1 and 2. This workshop had eight participants (Table 1), which furthers the point mentioned in the previous paragraph that the number of participants may influence the group dynamics during deliberation.

Theme analysis

Throughout each workshop, we found that participants mainly touched upon the human welfare and non-human welfare considerations of oysters. Subthemes within each of those categories were also identified and defined (Table 4; Table S5).

Figure 6 illustrates percent occurrence per theme per stakeholder category with data from all workshops combined. Based on Fig. 6, we can see that 'Supporting Services' was a consistent theme discussed by all stakeholder groups (27% Academia; 30% Government; 29% Industry; and 24% NGO) whereas there was minimal occurrence by government, industry, and NGOs regarding the 'Cultural'

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Table 4 Definitions of themes for all workshops combined utilizing Applied Thematic Analysis

Human Welfare—When a person considers (WAPC) the direct and indirect benefits obtained from oysters	
Nutrition/Health	When a participant values oysters as a food source that is healthy (or not harmful) due to microplastic contamination. Additionally, when a participant refers to oysters as a large-scale, sustainable food source
Cultural	WAPC the intrinsic benefits obtained from oysters
Economics	WAPC the economic benefits obtained from oysters
Non-Human Welfare—WAPC the needs of marine ecosystems following a non-anthropocentric perspective (e.g., environmental ethics)	
Ecosystem Health	WAPC the well-being of ecosystems
Supporting Services	WAPC an impact on the environment that causes further impacts on ecosystems and human systems

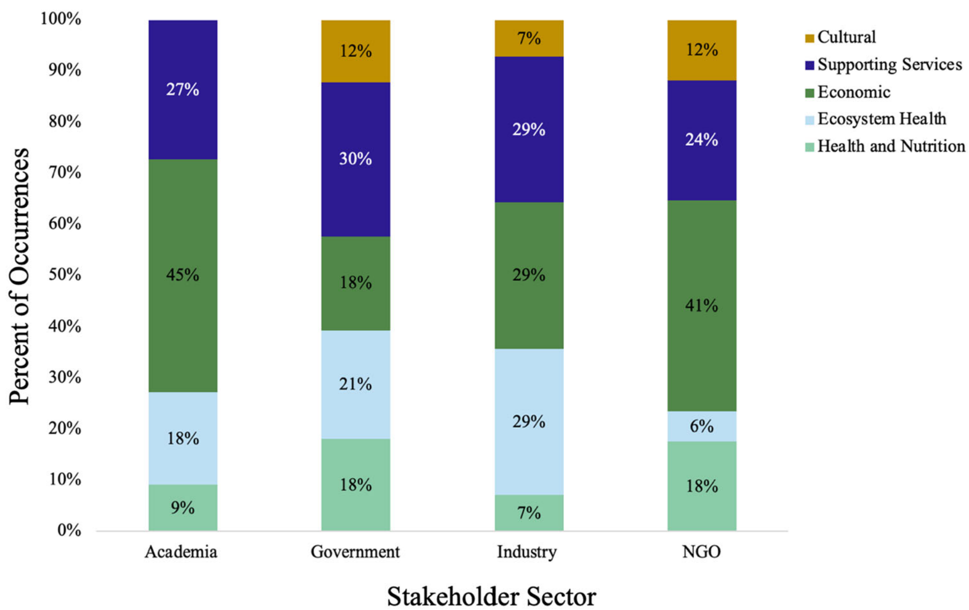

Fig. 6 Percent occurrence of themes discussed during deliberation per stakeholder category

Table 5 Definitions of Science and Policy Considerations

Science and Policy Considerations—When a person considers (WAPC) the influence of political or scientific entities	
Scientific Uncertainty	WAPC the probability threats actually causing significant impacts, especially as related to a lack of significant research
Policy/Regulation	WAPC the impacts of regulation on oyster businesses
Public Perception	WAPC general public understanding of oyster impacts as communicated by media, science, or policy
Science Communication	WAPC the ways research on microplastics is presented to the general public and to regulatory entities

theme and no occurrence for that theme by academia (0% Academia; 12% Government; 7% Industry; and 12% NGO).

In addition to the themes and subthemes described above, we wanted to understand the role science and policy played in the value-forming process. These are defined in Table 5.

As seen in Fig. 7, 'Policy and Regulation' was primarily discussed by government stakeholders but was not implied by any stakeholders in the industry category. 'Public perception' was an important topic as it was discussed at a high percent by each of the sectors (29% Academia; 33% Government; 43% Industry; and 47% NGO). 'Scientific uncertainty' (36% Academia; 13% Government; 43%

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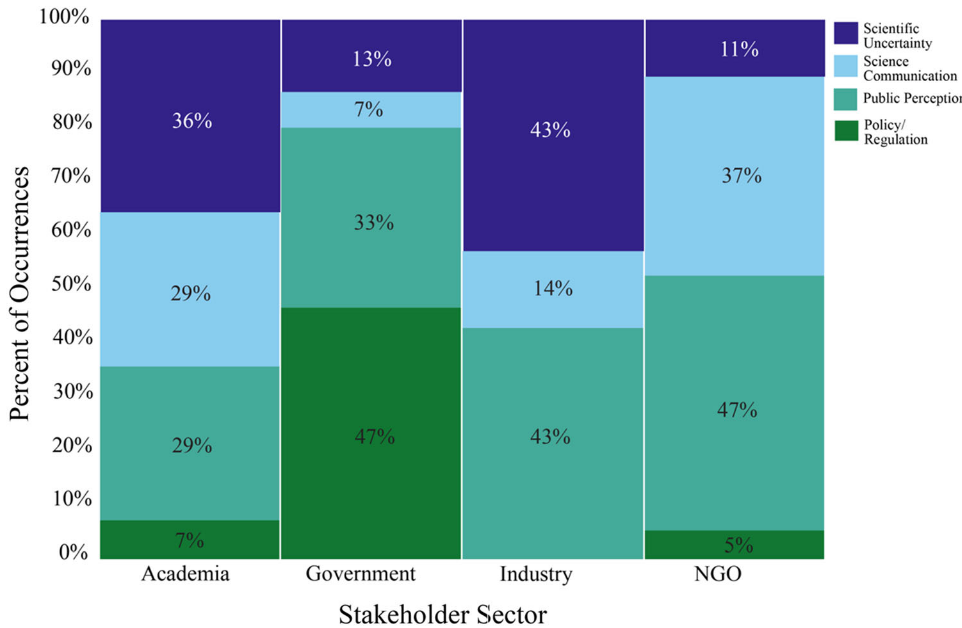

Fig. 7 Percent occurrences of Science and Policy Considerations discussed during deliberation per stakeholder category

Industry; and 11% NGO) and 'Science communication' (29% Academia; 7% Government; 14% Industry; and 37% NGO) were given relatively the same weight by academic and government stakeholders; however, there is a stark contrast between the percent of occurrences for those two by industry and NGOs. This could suggest a misunderstanding of how those two ('Scientific uncertainty' and 'Science communication') in practice are similar yet different.

DISCUSSION

Microplastics have been found in oysters in a variety of environments throughout the world (Keisling et al. 2020; Addo et al. 2022) illustrating that microplastics can be filtered, ingested, and egested. Additionally, oyster reefs have been found to have high concentrations of microplastics in the sediment suggesting sediments may be collection sites for microplastics (Hammadi et al. 2022). Results from this study indicated that the stakeholders viewed the threat of microplastics to oysters in a wider system context, meaning the stakeholders considered how microplastic ingestion could impact the role of oysters as ecosystem engineers or as important economic and cultural resources. This research highlighted socially important avenues for future scientific research on microplastic impacts on oysters.

The importance of the DMCE method

Evaluating complex environmental issues is challenging, and the DMCE methodology provides an appropriate framework to untangle the complexity of microplastics polluting oyster habitats. To our knowledge, this is the first study that utilized the DMCE methodology to introduce stakeholders to the idea of a 'microplastics ocean' by assessing various socio-, economic, and environmental indicators related to oysters. Our findings highlight the importance of methods that create social learning opportunities and contribute to value formation through deliberation and reasoned dialogue in making legitimate decisions for environmental issues. Given that public will is essential for supporting policies to reduce microplastic pollution in water, applying DV methods and exploring stakeholders capacity to do so could give us insights and knowledge to scale up these approaches (Eriksson et al. 2019; Wironen et al. 2019). For example, there is currently a call for stakeholder involvement in a global treaty to end plastic pollution and it is critical to adopt meaningful deliberation processes for making informed decisions to address marine microplastic pollution at a global scale (United Nations Environment Programme 2022).

We looked to evaluate how the stakeholders discussed and interacted with each other on the topic of microplastics polluting oyster habitats using hypothetical scenarios. Utilizing the DMCE method, we were able to structure workshops that required stakeholders to complete a specific, quantifiable assessment task. In doing so, a rich

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discourse occurred that allowed us to qualitatively understand the reasoning behind participants' choices.

No significant difference was found across stakeholder groups nor workshop dates (Fig. 3) (Mavrommati et al. 2017; Borsuk et al. 2019). These results show that the participants were able to complete the individual assessment twice, and most importantly, the participants were able to reach consensus as a group, regardless of the groups makeup (Table 1). Consensus was strongly encouraged, but not a requirement for workshop completion. The ability to reach consensus may be explained by the structure of the DMCE method in which participants are encouraged to ask clarifying questions of the experts (see 'clarifying instructions' in Table 3 and Fig. 4), and the facilitator and hosts are able to interject if participants are not following the instructions. Here, we associate completion of the individual and group assessments with the understanding of the assessment task. Altogether, the method (1) allows for a two-way information flow among hosts, experts, facilitators, and stakeholders (Mavrommati et al. 2017) and (2) provides tools for ensuring that participants understood the assessment tasks to be performed. Adding the idea of procedural considerations in the analysis of DV experiments could help us get helpful information and consider additional measures for future DV experiments, such as clarity of the assessment task and the quality of scientific knowledge.

The ability of each workshop group to reach consensus also suggests that stakeholders representing different categories (and, thus, different agendas) can come to an agreement on this complex microplastics issue. Interestingly, because of the qualitative output from the DMCE method, we were able to track how stakeholders interacted (Fig. 5). The importance of this is twofold. Firstly, since microplastics are considered a complex problem, different stakeholders will be involved in varying research questions for decision-making. Here, we were able to show that positive interactions intra- and inter-stakeholder groups can occur (Fig. 5). Secondarily, a key element of discourse-based valuation is reasoned dialogue between participants. Group dynamics and other factors such as facilitation skills can oftentimes dictate a particular outcome (Voinov and Bousquet 2010), but here we see the group relying on each other through numerous, quantifiable interactions (Fig. 5). This may have been influenced by the role of the facilitator who made sure everyone had the opportunity to speak. It's in workshop 2 that we see the greatest number of participants not outwardly agreeing with others (Fig. 5). This workshop had almost double the number of participants compared to the other two workshops (Table 1), suggesting that there is an upper limit to the number of participants that leads to effective dialogue.

The theme analysis illustrates how stakeholders value oyster resources through a 'microplastics lens' (Fig. 6). The experts provided their scientific knowledge to the stakeholders at the start of the workshop on the many uses of oysters in MA and how those uses influenced the indicators. The stakeholders then continued an in-depth discussion about the various ways that oysters contribute to human and non-human welfare during the deliberation process (Table 4; Fig. 6). Because of the qualitative output from the deliberative process, we were able to dissect those discussions further to quantify the specific considerations to determine the relative importance for each stakeholder group. Interestingly, no distinct silos were apparent; meaning no one theme dominated for a particular stakeholder group (Fig. 6). All themes, except for 'cultural,' were discussed by all stakeholder categories. This suggests that these stakeholders internalized the multiple uses of oysters and continued to bring them into the discussion with their peers. It also reveals that discussions pertaining to microplastics should include multiple stakeholder groups as a more robust dialogue emerges.

The diversity of themes and their relative importance within stakeholder groups (Fig. 6) suggests that stakeholders were able to think outside their traditional silos. This shows the role of DV methods in building the capacity of stakeholders to think holistically about environmental issues and creating space for integrating values to support decision-making (Pascual et al. 2017). The public 'alarm' pertaining to microplastics relates to the possibility that they will indirectly consume microplastics through their food (Rist et al. 2019). However, we found that all the stakeholder groups were not just considering 'health and nutrition' when discussing the implications of microplastic pollution in oyster habitats but were also considering the environment at large.

The perceived threat of microplastics was shown to permeate through the different uses of oysters, not just oysters as a human food source. 'Supporting Services' was one of the main topics discussed by each stakeholder group (Fig. 6). In this theme, the participant considered an impact on the environment that causes further impacts on ecosystems and human systems (e.g., microplastics cause a decrease in oyster populations which leads to a decrease in oyster reefs and habitats for other species and increases in coastal erosion). We see the main impact of microplastic pollution as perceived by these stakeholders—the microplastics may not cause isolated impacts, rather there could be rippling effects on the larger ecosystem and human system.

'Economics' and 'Ecosystem Health' represent the next themes with the higher frequencies across stakeholder groups. These themes in addition to 'Health and Nutrition' may be where the stakeholder silos could be the most

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evident. Interestingly, 'Health and Nutrition' was discussed at a lower percentage for the industry category compared to the 'Supporting Services,' 'Ecosystem Health,' and 'Economics.' Given that 'industry' reflects hatchery and business owners, it is surprising that that theme was not discussed more throughout that category. This could be explained by only a limited representation of this group being present during each of the discussions (Table 1). While not discussed at length, the 'Cultural' theme was discussed by each stakeholder category except for Academia. This absence within the academics could be due to an inherent silo within academics and/or the research focus of participating academics. Recent research has indicated the need to take a more transdisciplinary approach to studying plastic pollution (Riechers et al. 2021) and oyster management (Reeder-Myers et al. 2022).

Similar to the early years of climate change, microplastic pollution is an invisible threat characterized by uncertainty and delayed effects on human and ecological systems, resulting in a lower urgency to support a policy framework that could control microplastics (Riechers et al. 2021; Reeder-Myers et al. 2022). Even with the encouragement of discourse and the presence of experts, communicating microplastic science still needs to be improved. Our analysis provides a better understanding of the areas in decision-making that needed more robust attention (e.g., the cultural importance of oysters).

When the science is uncertain and/or the communication of that science is still poor, that is when perceptions may get skewed by all stakeholders, including the public. The rippling effects from these decisions could impact other perceptions and supply chains. Research by Kecinski et al. (2018), for example, showed that even when consumption of a certain product does not increase the associated risk, people may shy away from the product because it previously came in contact with a 'contaminant.' The research described by Kecinski et al. (2018) emphasizes the fine line between the communication of information relating to microplastics in oysters and the public's willingness to consume. Various stakeholders brought up the idea of scientific communication and public perception (Fig. 7). 'Public perception' was discussed with the highest frequency for every stakeholder group compared to the other social considerations. This shows stakeholders care about public perception, but other areas (e.g., scientific uncertainty and science communication) must be better addressed so that the public can perceive the information accurately. Even though we invited representatives of the general public (e.g., other non-governmental organizations), they could not participate in our workshops. Future research on this topic needs to focus on the perceptions and beliefs of the general public and devote more resources to recruiting them in deliberative processes.

A proposed decision-making process for microplastics

This research emphasized the need for a comprehensive decision-making process for microplastics. Plastics are a complex problem further complicated by multiple stakeholders as well as moral, ethical, political, economic, and social considerations (Koelmans et al. 2017; Rist et al. 2018; Potting et al. 2021). Our analysis supports the concept that making informed decisions arises from a shared understanding produced by effective interaction and discourse among stakeholders.

Figure 8 illustrates the suggested comprehensive decision-making approach and shows that the 'Social Assessment' is integral to this approach. Here, an 'environmental assessment' reports on the presence and impacts of a particular contaminant in the environment. A 'social assessment' then engages with society (e.g., stakeholders) to understand their perceptions and values of the environmental contaminant and how those perceptions may influence their own behavior. The composition of stakeholders involved may look different based on the environmental contaminant being discussed. Data obtained during the 'Social Assessment' phase could trigger a more specific environmental assessment. In this scenario, an important question would have been raised by stakeholders, yet there is no available science to answer it to date (e.g., do negative impacts of microplastics on oyster larval growth affect the adult oyster?). Alternatively, or in conjunction, the social assessment could illuminate the need for effective science communication or educational programming so that the public and stakeholders are well informed about the environmental contaminant. After several iterations, the environmental and social assessments could lead to solutions. In some cases, an environmental assessment could directly influence solutions (e.g., US Microbead Free Waters Act). Arguably, this direct linkage between an environmental assessment and solutions could be described using the precautionary principle. Alternatively, solutions could identify gaps and thus direct more research for a more robust environmental assessment (e.g., US Save Our Seas Act 2.0).

Whereas researchers can engage at any part of this schematic, we note that some form of an environmental assessment must happen first to show that there is a problem (or a potential for a problem), even if it is hypothetical. Having proactive dialogues for complex, transdisciplinary problems can indicate areas for more scientific research and highlight the feedbacks and importance of environmental education and science communication in social assessments. For this research, we initiated the decision-making process at the 'social assessment' section utilizing the DMCE methodology. This particular

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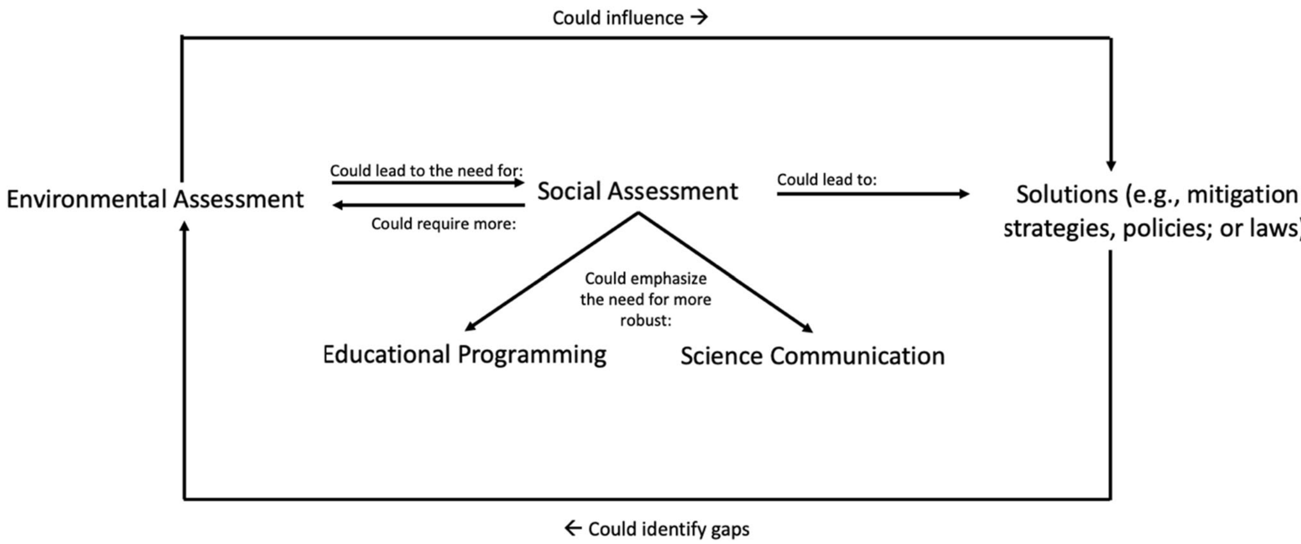

Fig. 8 A novel and comprehensive decision-making approach for microplastics. An 'environmental assessment' reports on the presence and impacts of a particular contaminant in the environment. A 'social assessment' then engages with society (e.g., stakeholders) to understand their perceptions and values of the environmental contaminant and how those perceptions may influence their own behavior. Data obtained during the 'Social Assessment' phase could trigger a more specific environmental assessment. After several iterations, the environmental and social assessments could lead to solutions (e.g., mitigation strategies, policies, or laws)

methodology provided us the opportunity to collaborate and co-generate knowledge with oyster stakeholders in MA as we explored how microplastic contamination in oyster habitats may affect their uses of oysters in future.

The workshops indicated that before stakeholders could advance to solving the problem (via mitigation strategies, policies, or laws) of microplastic pollution in oyster habitats (the implied 'goal' of Fig. 8), they still needed more information. Specifically, the stakeholders needed information pertaining to:

- *Environmental Assessment (specific to 'Risk Assessment')*—specifically stakeholders were interested in understanding the impacts of microplastic pollution on human health so that they could make better, more informed decisions in terms of their rankings. Blackburn and Green (2021) have also highlighted the need for more clinical trials on microplastic impacts on human health.
- *Environmental Education*—the 'social assessment' elucidated two needs for more environmental, transdisciplinary plastic education. Firstly, there is a cultural aspect of oysters that was discussed at points throughout deliberations (Fig. 6)—the importance of keeping local waterways clean (in this case, free of microplastic pollution) so that people can have the continuity of learning from their family how to harvest one's own food. Secondly, 'public perceptions' was an acknowledged important theme (Fig. 7); environmental education at all ages can influence public perceptions of complex problems.
- *Science Communication*—science communication is a critical tool that can inform public perceptions and stakeholders. As discussed previously, sometimes the results get skewed when misinterpreted by the non-scientific community. During discussions throughout the workshop, there was a lot of emphasis on the need for more robust science communication so that the stakeholders could better understand the issue (Fig. 7; Table 5).

In summary, decision-making is a nonlinear iterative process that requires the integration of people and sciences. As a result, solving complex environmental problems does not only depend on an environmental assessment but it requires environmental education and science communication in order to build a shared understanding at local, regional, and global scales where decisions are taken.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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