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A necessary diversity of perspectives in decision-making regarding deep seabed mining: implications for science, people, and the environment

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The transition from the current fossil fuel-based economy toward one that relies on renewable sources of energy allegedly will require a set of minerals for manufacturing batteries that store this energy and power electric devices. Deep seabed mining (DSM) is an economic activity that has the potential to fill these material requirements as it relies on collecting rich mineral resources from the bottom of the ocean. This activity brings enormous challenges to regulation and potentially irreversible impacts on a large scale. In addition, the seabed is considered a common heritage of humankind, and therefore, questions of distributions of burdens and profits also emerge. We build on the premise of social justice, legitimacy, and participatory processes to discuss six perspectives that should be considered while dealing with DSM. We claim that DSM should be seen through a wicked problem lens, acknowledging the limits of ignorance squared, inside a scientific paradigm open to the possibility of a post-normal science. Participation should center on recognizing plural rationalities, ensuring justice and capabilities, and actively including the global South. We conclude that DSM's legitimacy can be enhanced by following these six perspective guidelines.

KEYWORDS

seabed mining, precautionary principle, cultural theory, worldviews, adaptive management

Background

Transitioning from a hydrocarbon-based society to one more reliant on renewable energies would allegedly require the provision of minerals that enable reducing the carbon footprint resulting from human activities. Deep seabed mining (DSM) is an emerging industry that has the potential to fill these material requirements necessary to meet energy demands without relying on fossil fuel matrices. The minerals of interest for DSM, including rare minerals—also critical for manufacturing batteries that store energy produced from renewable sources and power electric devices, such as cars, bikes, and vessels—can be found in distinct locations at great ocean depths. The demand for batteries is expected to soar during this century (IEA, 2021); thus, DSM can be an attractive activity. While commercial DSM technology is being developed (Jaeckel et al., 2023), it brings enormous challenges in terms of regulation, and the environmental and social impacts remain poorly known. Considering the seabed in areas beyond national jurisdiction as the common heritage of (hu)mankind (UNCLOS, 1982)

further complicates the issue. We claim that broader perspectives that go beyond usual costs and benefits—which recently have questioned the feasibility of parts of this industry (Sumaila et al., 2023)—and procedural environmental impact assessments are crucial and timely.

The technologies employed to extract minerals vary according to the targeted resource and environment where activities will take place. Currently, minerals of interest are described to occur in three main types of deep-sea deposits (Heffernan, 2019; Miller et al., 2018): (1) the abyssal plains, where mineral nodules occur; (2) the metal-rich crust, covering seamounts thousands of meters above the abyssal plains [rich in Cobalt (Co), Platinum (Pt), and Molybdenum (Mo)]; and (3) seafloor massive sulfide deposits, formed around hydrothermal vents rich in Copper (Cu), Lead (Pb), Zinc (Zn), Gold (Au), and Silver (Ag). The ecosystems in which deep-sea minerals form have particular physical and chemical characteristics and present distinct biodiversity groups. For instance, abyssal regions are low-energy environments, where biological communities feed mostly from the sediment rain (marine snow), with polychaeta, sponges, sea cucumbers, crustaceans, starfish, microorganisms, and other small animals living between the grains of sand, near or on polymetallic nodules. Seamount environments include mainly sessile epifauna such as corals, anemones and sponges. Such ecosystems connect benthic and pelagic ecosystems, being used by a diversity of megafauna (e.g. sea turtles and marine mammals) for resting and feeding (Miller et al., 2018). Seafloor massive sulfides occur in environments of hydrothermal vents, which also display diverse and specialized life forms including giant worms, crustaceans and molluscs. Deep-sea biodiversity, as well as the extension and magnitude of the impacts arising from DSM, including direct, indirect, and cumulative impacts (Jaeckel et al., 2023), remains vastly unknown (Levin et al., 2020).

Different narratives surround discussions about DSM. On one hand, it is compared to land-based mining, with some arguing that DSM will probably have fewer impacts, especially regarding deforestation, community compulsory displacement, and child labor, among others (Hyman et al., 2021), and will probably operate with a smaller carbon footprint in its life cycle when compared to equivalent land-mining activities (Paulikas et al., 2020). On the other hand, apart from the numerous direct and indirect environmental impacts expected from DSM activities (Miller et al., 2018), some authors argue that DSM may actually exacerbate environmental and social pressures on land as it represents an additional source of competition for resources (Singh, 2021a). Conversely, deep-sea ecosystems are known to provide a wide range of ecosystem services (ES; Armstrong et al., 2012; Folkersen et al., 2018; Le et al., 2017; Thurber et al., 2014), including regulating services (carbon, nitrogen, and phosphorus cycles), often cycled via microbial functions (Orcutt et al., 2020); biodiversity (Sweetman et al., 2019); provisioning (fisheries and genetic resources); and cultural services (La Bianca et al., 2023).

Considering that described deep-sea ES are non-marketed benefits—and existing cost–benefit analyses are explored to a limited extent (Chen et al., 2022; Sumaila et al., 2023)—the necessity of investigating their life cycle, from provision to use, including their interlinkages, synergies, and codependences, is critical for informed decision-making.

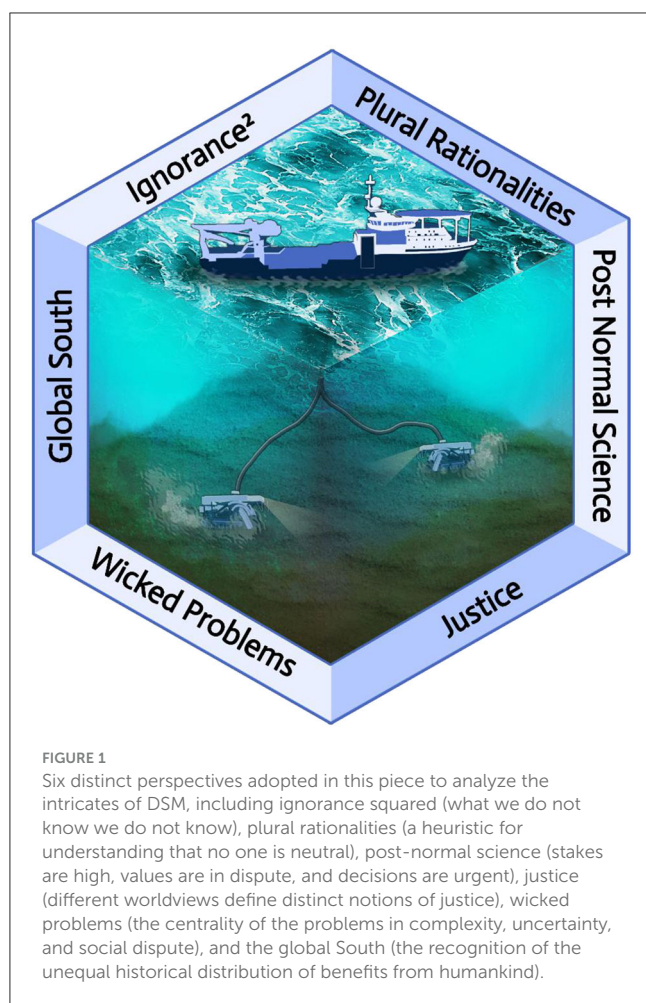
Negotiations around establishing a system that regulates the commercial extraction of seabed resources (exploitation), currently take place at the International Seabed Authority (ISA), a UN-affiliated organization established under the United Nations Convention on the Law of the Sea, responsible for regulating and managing DSM activities in areas beyond national jurisdiction (the Area) while ensuring the effective protection of the marine environment (UNCLOS, 1982—Article 145). DSM represents a unique industry with a supranational governance structure, which does not offer immediate parallels with existing industries (Menini et al., 2022); this can make local public participation challenging. In practice, the ISA shall act as a guardian to the minerals of the Area, which are classified as “the common heritage of (hu)mankind” (UNCLOS, 1982—Article 136). Furthermore, ISA activities should be carried out for the benefit of humankind as a whole (UNCLOS, 1982—Article 140). To date, the ISA has granted 30 contracts (one has been withdrawn) of exploration for conducting environmental, technological, and economic studies—with exclusive rights—around the globe, including the Atlantic, Pacific, and Indian Oceans.

The ISA comprises the signatory parties of UNCLOS, which includes 167 member states and the European Union. ISA governance comprises four active organs: the Assembly, the Council, the Legal and Technical Commission (LTC), and the Secretariat. The Assembly is the supreme organ of the ISA comprising all member states (UNCLOS, 1982—Article 165); the Council represents the executive body, consisting of 36 members elected by the Assembly (UNCLOS, 1982—Article 161); the LTC is a subsidiary organ of the Council responsible for formulating rules, regulations, and procedures, as well as to provide recommendations for Council’s approval (UNCLOS, 1982—Article 165); finally, the Secretariat is the administrative organ of the ISA (UNCLOS, 1982—Article 166).

Numerous obstacles remain that add to the challenges in developing an effective regulatory framework to manage DSM. The existing high-level uncertainties and knowledge gaps relating to deep-sea ecosystems’ structures and functioning and the potentially irreversible DSM impacts (including in the context of climate change); the alleged need to balance social and economic trade-offs, as well as apply a precautionary approach in light of a new industry arising; administering the several potentially conflicting interests at stake, including from public participation; and managing resources that are the common heritage of humankind are only some of the issues that currently represent challenges in the context of DSM negotiations. Considering the exposed, establishing a legitimate, transparent, equitable, participative, and robust system for governing and managing DSM activities requires reflections that address such multiplicity and complexity.

Justificative

There is support for a precautionary approach (e.g., ITLOS et al., 2011) regarding activities in the Area and the obligation from contractors, for instance, to deliver environmental impact statements when conducting equipment and system tests categorized by the ISA as having the potential to cause significant



harm to the marine environment during exploration and potential future exploitation (Guilhon et al., 2022). However, different sectors of society view the precautionary approach as a barrier to technological development and economic growth (e.g., Adler, 2011) and advocate for sound science to establish the regulations for their economic activities.

Such conflicting views are followed by existing processual pushes toward developing DSM activities on a commercial scale (Jaeckel et al., 2023; Pickens et al., 2024; Singh, 2021b), resulting in obstacles to decision-making. On one side, the discourse is that companies should act in a precautionary and adaptive manner to incorporate new knowledge and minimize impacts (Levin et al., 2020; Niner et al., 2018a,b), whereby mining projects can learn and develop more adequate practices while performing the activity, periodically incorporating further ecological, industrial, scientific, and policy developments into management as they are acquired (Durden et al., 2017). On the other side, for a situation in which DSM impacts may be irreversible, a “learning-by-doing” approach seems to conflict with the ISA’s commitment to “ensur[ing] the preservation of the marine environment”, raising concerns about DSM’s legitimacy (Jaeckel et al., 2023).

The current circumstances around DSM decision-making serve as an example of a context in which ideas regarding nature are in dispute (Leff, 2006; Table 1). Based on this, we propose to

explore the existing tensions from different rational angles. As the regulation of DSM activities currently represents a deadlock in decision-making, our contribution is to show that different rationalities should be considered regarding DSM’s future and its role in society. We echo the claim that DSM lacks legitimacy and that more participation is needed in the whole decision-making process (e.g., Jaeckel et al., 2023). Public participation is “designed to accommodate the needs and desires of the participants and to respect their view on legitimacy and fairness” (Menini et al., 2022), which could be an alternative for enhancing both social acceptance and DSM-derived local development. Nonetheless, as a large number of seabeds occur in areas beyond national jurisdiction, and therefore belong to all humankind, the very definition of what local public participation is remains an open discussion. This aligns with the perspectives we present in the following discussion as they necessarily advocate for broad participation and transparency regarding DSM activities throughout the process, including at the local, regional, and global scales.

To move forward, broadening participation requires recognizing other human–nature relationships, which is different from the tradition of seeing nature as something hierarchically inferior, available to be acquired, and transformed freely and as an object to be economically exploited for human benefit (Arriagada Oyarzún and Zambra Álvarez, 2019). There are other views (Fanon, 1968; Haraway, 2015; Islas-Vargas, 2020), values (Navarro and Gutiérrez, 2018; Tilot et al., 2021), and possibilities for different scientific paradigms (Funtowicz and Ravetz, 1993; Kuhn, 1962).

Based on the possibility of different social-ecological relationships, this article’s objective is to explore six perspectives, inviting the reader toward more reflexive and socially inclusive thinking, with the expectation of stimulating reflection on existing (and contrasting) points of view by using the DSM regime as a case study. The authors expect that the views explored here will provide a further step in the direction of reimagining and implementing a more legitimate, science-based, and plural decision-making process regarding DSM. Nonetheless, the perspectives explored here do not exclude others, such as those from indigenous peoples and local communities (e.g., Tilot et al., 2021), political ecology (e.g., Leff, 2006), and feminist studies (e.g., Navarro and Gutiérrez, 2018), but represent a structure for binding these multiple views and an invitation for broad considerations.

Required perspectives

This section presents six distinct perspectives (Figure 1) that are fundamental to the present article’s objective and contribute to exploring DSM issues in a broader context.

Ignorance squared

First is to consider the idea of the “ignorance of the ignorance” (or ignorance squared) regarding DSM. Usually, uncertainty is considered a space to be conquered by using more data and analysis, up to the point that it is considered arbitrarily acceptable: an optimal solution to the issue at stake. As described by Ravetz

TABLE 1 Overview of four cultural perspectives.

Worldview	Plural rationality perspective	Likely ideas applied to DSM	Example policies	Preferred type of power*	Ideas of justice**
Hierarchism (Nature is tolerant within limits)	Institutions are essential to ensure the fair distribution of resources in accordance with needs defined by experts.	Reliance on ISA experts, governmental policy; international treaties	Procedural solutions of laws and regulations; Adaptive management Research funding	Coercive (follow the law or go to jail)	Proportion (benefits are allocated in accordance with an administrative determination of rank, contribution, or need)
Individualism (Nature is benign)	Social life is the product of the actions of individuals who pursue personal goals.	Reliance on market and market-based solutions; new technologies	Neoliberal economics of profit and efficiency: “sustainable” industrial processes	Persuasive (buy this product and feel like in heaven)	Priority (equality of opportunity—achieved through successful competition).
Egalitarianism (Nature is ephemeral)	Equality among social actors is the greatest good.	Reliance on collective responsibility; lifestyle changes	Critical social science, equity, justice, and the precautionary principle	Moral (you are being bad to society, the environment, the poor ... when you...)	Parity (equality in condition—equal shares to all claimants)
Fatalism (Nature is capricious)	Chance dominates social relations.	Distrust of the ruling elite; media	Denies the necessity of environmental protection	Despotism (authoritarian leadership)	Amoralism (whatever is necessary for survival)

DSM, deep seabed mining; ISA, International Seabed Authority.
*See Allouche et al. (2019). For fatalism, see Verweij (2023).
**See Rayner (2006) and Rayner et al. (1999). For fatalism, see Verweij (2023).

(1993), ignorance squared becomes visible when specialists, usually certified disciplinary scientists with restricted (siloe) training, are in some way confronted with problems lying outside the safe domain of their puzzle-solving practice (i.e., a problem to which they are not specialists). As the decisions required currently constitute a much higher level of complexity—embracing aspects such as considering large time horizons, interconnections with other elements of nature and the broad society, and trade-offs regarding each managerial choice, among others—they push decision-makers into an interdisciplinary space much beyond the one covered by the knowledge they were trained with, acquired by a “normal-scientific practice, of the reduced, artificial and controlled environment of the research laboratory” (Ravetz, 1993). This interdisciplinary uncertain space requires opinion and judgment, a leap into the unknown realm of ignorance always followed by the ignorance squared (simply put, what they do not know that they do not know). The ethical implications of this leap are important (Jacomy and Borra, 2024) as it embraces value, participation, and recognition (i.e., what is good or bad and for whom) judgments, connecting ignorance to justice and recognition.

Ignorance squared can be conveniently illustrated by the usual shock that scientists with “objective views of problems” (e.g., from the natural sciences) feel when confronted with issues of social justice, politics, equity, gender, racism, participation, human behavior, and choice, among others. Taken broadly, conflicting views about what the knowns and unknowns (and what the best way forward is) impose questions on scientists’ fields of expertise that can only be satisfactorily answered by ignoring many other fields. To these questions, an elegant solution (a purely neutral and objective view of the problem) can hardly be considered without ignoring all the uncertainties and judgments that are its constituents.

Multiple perspectives (i.e., the understanding that siloe) knowledge is limited and not neutral; Ney, 2012), *humility* (i.e.,

the acknowledgment of ignorance; Scholz and Wellmer, 2021), and *reflexivity* (i.e., a critical reflection on what kind of awareness you have when doing what you are doing; Ampe et al., 2024; Lazurko et al., 2025) are the key words here. Having an open attitude about the possibility of being wrong and that other opinions and facts are also legitimate is crucial. Participation is a leverage for promoting legitimacy (Schadeberg et al., 2024); therefore, the dialogue between these often conflicting views and facts represents a legitimate way to progress. As current global problems such as climate change and DSM involve decisions that include great uncertainty about the future, impacts that will be unevenly distributed along regions and social groups, and effects spreading within a largely unknown time span, reducing the debate to a few sets of parameters (toward which an elegant solution can be provided) can only be made by ignoring a set of different views about what the problems are and how to solve them.

Wicked problems

Wicked problems (Head, 2022, 2023) represent a class of persistent, complex, ill-defined problems that often occupy a socially contested terrain and therefore require much more social participation and deliberation than “tame” problems (i.e., familiar problems for which a robust solution is well known and commonly accepted). The starting point for understanding wicked problems is to understand scientific ideas (and the consequent management practices) are by-products of an age, influenced directly or indirectly by the social foundations in which they were created. Knowledge is, thus, socially, historically, and culturally dependent (Latour, 2013). There cannot be a neutral foundation for comprehension, and a strictly objective verification is not possible (Barlas and Carpenter, 1990). The idea of pure knowledge, independent of social and historical processes, must be abandoned

for more flexible ideas that are interdisciplinary, where the absolute truth from formal rigor opens space for more functional perspectives: “The academic ‘soundness’ requires the rigor of a kind that, in these gray interdisciplinary areas was simply not there to be had” (Toulmin, 1977).

This second perspective understands that some complex problems regarding society can be taken as wicked or messy (instead of tame) problems (DeFries and Nagendra, 2017; Ney, 2012; Rittel and Webber, 1973; Verweij et al., 2006). Examples include, but are not limited to, climate change, obesity, transport in large cities, immigration, many types of human–nature relations, and DSM. In the wicked problem view, public goods are in dispute, meaning that public policies cannot be correct or false; they always depend on each social group that these policies represent or exclude. Public policies cannot propose an “optimal solution” because what is optimal for one group might be the obliteration of others. This perspective sees the boundaries of the pressing problems, of which DSM is part, as becoming less clear-cut as the connectivity of global society increases, and thus, far more dependent on framing, debate, and controversies, by-products of a plural society. In short,

“in a pluralistic society, there is nothing like the undisputable public good; there is no objective definition of equity; policies that respond to social problems cannot be meaningfully correct or false; and it makes no sense to talk about ‘optimal solutions’ to social problems unless severe qualifications are imposed first.” (Rittel and Webber, 1973)

Any goal for adaptation (Adger et al., 2009) or resilience (Oliveira et al., 2024) is not an immutable threshold that comes from a neutral point of view (e.g., in the best interest of all); on the contrary, goals are socially constructed and dependent on ethics, knowledge, attitudes to risk, and culture, which are underpinned by diverse values (Adger et al., 2009; Ney, 2012). Choices regarding DSM, such as where it should happen, to what extent, to what purpose, and so on, are necessarily in the realm of social choice. These questions, thus, require a legitimate democratic debate and participation, which raises questions about the ISA’s role as a legitimate participative arena where decisions are taken (e.g., Jaeckel et al., 2023).

The idea of wicked problems was previously suggested to be embedded in ecosystem-based management (EBM; Berkes, 2012), with an emphasis on the long-term unsolvable trait of these kinds of problems. We echo the necessity of using the wicked problems lens and bringing EBM into the present discussion as it can be an appropriate and innovative management style for DSM issues (by incorporating guiding principles such as “considering the dynamic nature of ecosystems”, understanding that “society is embedded in the ecosystem”, understanding the “necessity of an adaptive management”, having a “complex view of systems”, etc.; Guilhon et al., 2021). However, some EBM principles, such as “a necessity of stakeholder involvement” and that “decisions involve social choice”, were previously taken with lower relevance when compared to other principles (e.g., considering ecosystem connections), both within the regulatory DSM framework (Guilhon et al., 2021) and stakeholders’ perceptions (Guilhon et al., 2023);

therefore, it requires complementary attention. We want to emphasize that the plural perspective of wicked problems is a crucial trait as it is connected to the other perspectives described in this article (e.g., cultural theory, indigenous and local knowledge, and the global South). We claim stakeholder involvement must go much beyond a routine practice of inviting the community to provide comments on documents, for instance. It should include establishing multiple channels of communication and participation in the community, where active consultation and listening sessions involving different stakeholder groups can take place. The process needs to change toward a co-creation practice, which promotes the centrality of a diverse understanding in defining and framing global challenges, such as climate change and DSM. Although time and resource-consuming (i.e., inefficient), adopting a position in which plural perspectives—often conflicting—are present, is the necessary democratic and legitimate way forward in opposition to a single-minded (i.e., elegant) solution.

Post-normal science

The interdisciplinary perspectives presented so far are coherent with and complemented by the third perspective of this article, the idea of post-normal science (Funtowicz and Ravetz, 1997). This idea emerges from what Kuhn (1962) described as normal science. For the author, *normal science* refers to the routine puzzle-solving practice in which the scientific practice delves between two conceptual revolutions. In this normal state, uncertainties are managed automatically, values are unspoken, and foundational problems are unheard of Funtowicz and Ravetz (1993). By comparison, in post-normal science, the centrality comes from the understanding that “facts are uncertain, values are in dispute, the stakes high and decisions urgent” (Funtowicz and Ravetz, 1993). This perspective enhances the idea of stakeholder consultation in broader and deeper participation, expanding the usual understanding of stakeholders, commonly restricted a group of specialists from the scientific community (plus a few “relevant” decision-makers), to the broad community (namely, expanded peer community) based on the justification of shared risks to the globalized civilization. The authors’ argument shows that in a context in which the uncertainties and stakes are high such as DSM, the possibility of normal puzzle-solving science is inadequate. For instance, a parallel from the land mining sector showed that science can evolve into a “professional consulting” practice (Pérez Cebada, 2016), changing the traditional role of experts (i.e., the jump into the unknown realm of ignorance). This new “professional consulting” practice of science often reveals conflicts between distinct schools of scientific analysis, where the same data can tell different stories (Gould et al., 2025). In addition, stakeholders and companies use different “valuation languages”, leading the process of decision-making far beyond that of what normal science is used to participating in (to the benefit of the industry; Pérez Cebada, 2016). Finally, as extensively debated by Beck (2014), the current global society is additionally surrounded by several types of risks, as society itself is the origin of many of them, in a self-reinforcing risk-creative mob that

enhances the uncertainty about their relations with and inside the surrounding environment.

Theory of plural rationalities

How much diversity is enough? What is the minimum level of diversity the decision-making process of wicked problems must embrace? These are very important questions that connect what has been said so far with our fourth perspective: the theory of plural rationalities, or cultural theory. A plural view of society, as described by the theory of plural rationalities (Douglas and Wildavsky, 1983), understands scientific work (and any consequent decision-making process) as intrinsically biased, despite the claims of neutrality of a siloed community. The basic assumption, corroborated by decades of argument (e.g., Chuang et al., 2020; Rayner et al., 1999; Schwarz and Thompson, 1990; Thompson, 1997; Verweij et al., 2006), is that social relations provide individuals and groups with normative and cognitive tools to understand the world. The attribution of meaning to a situation or, more specifically, the choice of facts and certainties about a problem does not happen in a vacuum. It is embedded and influenced by a set of socially constructed and reproduced shared values and beliefs (i.e., culture) that represent viable forms of social relations. Therefore, politics, decision-making, technology, and social choice are understood as being dependent on cultural backgrounds, and these shared values and beliefs (or worldviews) provide heuristics (Schwarz and Thompson, 1990; Thompson, 1997) that help understand what the necessary minimum diverse groups are.

The theory categorizes worldviews according to group-grid dimensions (Thompson et al., 1990). These include (1) hierarchist, (2) individualist, (3) egalitarian, and (4) fatalist (Table 1). Although originally proposed as an anthropological classification, the typology has found great utility in terms of understanding one's environmental perception and attitudes. The typology serves to underscore the challenges that emerge in policy negotiations when the parties have orthogonal starting positions and perspectives.

This heuristic is important as it helps ensure that necessarily opposing views about what the problem is and how to solve it are brought to the table. In DSM issues, they are relevant as this typology from culture theory represents the different biases in understanding the relations between humans and nature, in a close match of what Holling (Gunderson and Holling, 2002; Holling, 1986) called "Myths of Nature". In addition, with this framework, conflicting perspectives about the pressing problems can be understood and managed by a conflict-reducing heuristic (Ney, 2012; Oliveira, 2022; Scolobig et al., 2016), namely, a clumsy solution. A clumsy solution reflects a punctual agreement between conflicting perspectives. Different from consensus (broad convergence of thoughts and beliefs), clumsy solutions operate in a zone between these worldviews where consensus is not possible. As their views of the problems and solutions are in opposition, there cannot be an unrestrictive convergence. What might happen then, under a determined set of conditions (Oliveira, 2022; Sabatier and Jenkins-Smith, 1993), is a compromise (Scolobig et al., 2016), which might emerge from the specific aspects of the issue at stake

on which these worldviews can agree, resulting in an increasingly legitimate solution with a reduced potential of sabotaging each other. A consequence of this process is that the solutions are always suboptimal, provisional, and somehow ephemeral yet legitimate (Ney, 2012; Oliveira, 2022).

Justice

These worldviews from culture theory imply that different conceptions of justice emerge from each group. For the individualist, the main idea of justice is priority, where justice comes from a successful competition: the first in time, the first in right (Rayner et al., 1999). For hierarchy, justice means proportion, a distributive outcome comes from an administrative determination of preference (rank, contribution, or need). Finally, for the egalitarians, parity is the goal, meaning an equal share to all claimants or, based on the egalitarian view of a flat society, that all people must end in the same final (equal) position. These views bring about debate regarding what kind of goods and benefits allocation, as well as the decision-making process for allocating risks and damages, society should take. Following the idea that the historical processes of human society have privileged one part of the society to the detriment of the other, assuming a priority principle would hardly diminish the gap between the already privileged group to the usually excluded or marginalized ones. Recognizing diverse groups and that humankind faced history from distinct sides of the economic development process must thus be the first step toward a reasonable idea of justice.

A useful understanding of the main concepts around justice theory applied to environmental issues (Schlosberg, 2007) moves beyond classic ideas on distribution (Rawls, 1971) in at least three other aspects: recognition, participation (or procedure), and capability. From the distributional aspect of justice also comes recognition questions, such as those related not only to how the resources were distributed among the beneficiaries (priority, proportion, or parity) but also to why they were distributed among that group of beneficiaries. For Young (1990), the main cause that determines distributional injustices comes from a lack of recognizing social differences among groups, or individuals, and the consequent practices of oppression and domination. There is therefore an alignment of recognition with the proportion principle, as for the latter to work properly, the former is crucial. Recognition, finally, brings one to admit that people have different identities and histories and that policies and institutions should not only divide the benefits in fair shares but among the full diversity of groups of that society, toward which historical asymmetries must be acknowledged and compensated (Legg et al., 2023; Young, 1990). The idea of equality (understood as an equal distribution of goods) must give room to equity, where fairness between genders or any marginalized groups, usually race, social classes, and their intersectionalities (Arriagada Oyarzún and Zambra Álvarez, 2019), recognizes that these groups start from places of disadvantage, with imbalances that must be addressed (Legg et al., 2023); thus, equity also matches with the parity principle.

People and groups, once recognized, must have the right to have their voices and necessities heard in the decision-making

arenas. Participation (or procedure) therefore is about the roles that different social groups take during the decision-making process (Schlosberg, 2007) that govern the distribution of benefits and duties, risks and damages. The relevance of participation follows the fact that representatives channel the influence of those being represented: Women's movement activists from all over the world claim that legislatures formed by a majority of men cannot properly represent women (Young, 2000). The claim for procedural participation is understood as a condition to increase DSM's legitimacy (Jaeckel et al., 2023).

The demand for recognizing and including different types of knowledge, including those from indigenous peoples, in decision-making regarding DSM is growing (Escobar et al., 2021; Morgera, 2024; Tilot et al., 2021). In addition, the voices of movements representing younger generations have also gained space within global decision-making forums (Dobush et al., 2022), including the ISA. Youth representatives advocate for the right to live on a more promising planet, able to maintain balanced social, economic, and environmental needs. In addition, current and future generations are the guardians of mineral resources found in the Area, as these are the "common heritage of (hu)mankind" (UNCLOS, 1982).

Another complementary view of justice, capabilities, is part of our perspective as it contributes to an unusual perspective of justice. *Capabilities* mean the freedom to live different types of life (Sen, 1993). It represents a person's real opportunities to do and be in the context of a determined society (Pressman and Summerfield, 2002). Capabilities represent something fundamental to each human being: "core human entitlements that should be respected and implemented by the governments of all nations, as a bare minimum of what respect for human dignity requires" (Nussbaum, 2007). This approach has recently been shown to be more conducive to sustainability and compliance in the aquaculture sector (Samerwong et al., 2020), and several governance capabilities (such as reflexivity and resilience) are crucial for coping with wicked problems across scales (Termeer et al., 2016). Equity and capabilities look aligned with ideas of proportion, parity, participation, recognition, and plural representations that, we claim, are necessary and integral parts of a legitimate democratic process that are appropriate for the DSM case, as risks and benefits will be unevenly shared along society (e.g., Leff, 2006).

Global South

The globalization process connected the whole planet, accelerating the processes of economic growth and resource extraction—or conflation in Lopez's (2007) words—toward a hyper-connected world, but the promise of a global community does not include the whole society at the same level of wellbeing, comfort, security, and access to goods and benefits that emerged from this process (Leff, 2006). Nonetheless, not only were the blessings unevenly shared, but in this society, the risks and damages (Beck, 2014) are also shared disproportionately. In the globalization dream, part of the global community was kept in privilege while the other was pushed into a disadvantaged position (Gray and Gills, 2016). The idea of a global South is the manifestation of this inequality:

What defines the global South is the recognition by peoples across the planet that globalization's promised bounties have not materialized, that it has failed as a global master narrative. The global South also marks, even celebrates, the mutual recognition among the world's subalterns of their shared condition at the margins of the brave new neoliberal world of globalization. (Lopez, 2007)

The global South is not only formed in geographical opposition to the global North (the United States and Western European countries) but is also intertwined with these societies and territories as a fractal reproduction of the global South–North disparity. Influenced by different locally bonded nuances inside each part of the global North territories lies a part of the global South, where the geographical boundary gives space to other types of segregation criteria (Lopez, 2007), such as race, gender, class, ethnic origins, and all possible intersectional combinations of minorities (e.g., Arriagada Oyarzún and Zambra Álvarez, 2019), including those at the local scale that are affected by the DSM activity along any of the phases of its life cycle. For instance, some guidance on how to approach the local scale could follow those from land mining (e.g., Menini et al., 2022). Feeding back to the justice topic, recognizing these marginalized elements (i.e., gender, race, intersectionality, etc.) in terms of unfair access to goods and benefits and the overwhelming share of risks and damages is crucial.

The global South topic is relevant to the present piece for many reasons. First, the global South is underrepresented in the decision-making regarding DSM (Jaeckel et al., 2023). Second, in the global South perspective, economic and cultural cooperation, human rights, and promoting world peace (Gray and Gills, 2016) are all crucial for constructing the legitimate governance of DSM. Third, the premise of justice and equity makes these issues central. Last, but not least, if DSM brings uncertainties and risks to be shared by the global community but directly benefits only a small number of companies and countries, historical inequalities are reinforced, and the nationalism/racism divide is enhanced, finally reducing the promise of a prosperous and sustainable future for all humankind—the rightful owners of the areas beyond national jurisdiction (UNCLOS, 1982)—into fallacy.

Recommendations for future research and governance

Some recommendations would include creating a public database of cases regarding DSM beyond the environmental data available from the DeepData database (Rabone et al., 2023) in terms of public control, which includes governance data, public participation histories, perceptions, and manifestations revealing both cases of failure and success, allowing future DSM cases, or other areas society may explore, to learn from and build a more just society. In addition, effective strategies for involving local stakeholders in DSM decision-making processes must be made and followed, enhancing the guidance used in land mining (e.g., clarity on who is responsible for consultations; consultations during the prospecting, exploration, and exploitation phases; and the representation of civil society on decision board and others listed in Menini et al., 2022), legitimacy, and transparency in the activity.

Reflexivity statement

All the authors of the present study, three men and one woman, are white and originally educated in South and North America and Europe. Two are early-career researchers, two are senior scholars, and one is also a professor. All currently live in the northern hemisphere and are active participants in the pursuit of social-ecological methods to address the challenges of ocean sustainability.

Final remarks

Promoting a humble view of nature, especially the relationship between humanity and nature, is a necessity. The idea that nature is a subordinate space that can be exploited, reconfigured, manipulated, and transformed freely according to the necessities and views of a dominant economic and scientific elite must be abandoned for legitimate, democratic, inclusive, and participative practices of governance and scientific progress.

In this article, we focused on DSM as it configures a situation in which the promises of a great and green future bump up against the old practices of ignoring our ignorance, promoting exclusion, and distilling elegant solutions to problems that might reinforce historical privileges on the access to goods and burdens of human-nature governance.

We briefly identified and discussed six dimensions that aimed to bring a new understanding of DSM, from the perspective of an equal and just society for the future of humankind. From our understanding, the first step is to accept the limits of our knowledge (the ignorance-squared perspective). Also, the current problems, DSM included, are context-dependent and socially formulated (wicked problems and post-normal science perspectives). For these kinds of problems, diverse participation (the cultural theory, justice, and global South perspectives) is the key, and ensuring plurality is the proper ethical choice for the future.

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.

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Author contributions

BO: Conceptualization, Formal analysis, Methodology, Writing – original draft. BF: Writing – review & editing. IG: Supervision, Writing – review & editing. MG: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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