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Hugging the Shore: Tackling Marine Carbon Dioxide Removal as a Local Governance Problem

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This Perspective explores the local governance of ocean-based carbon dioxide removal (CDR). Proposals to enhance the ability of oceans and marine ecosystems to absorb atmospheric CO_2 are often discussed as examples of "geoengineering," but this framing obscures the site-specific nature of most of the suggested interventions. The Perspective outlines some of the key local dimensions of marine CDR as currently imagined, and suggests a framework for increasing local participation in its assessment. Robust processes of local participation are essential to address the place-based conflicts that are bound to emerge if any of the proposed methods of CO_2 removal is ever deployed at scale.

Keywords: carbon dioxide removal, geoengineering, governance, marine environment, ocean-based carbon dioxide removal, ocean alkalinity enhancement, ocean iron fertilization

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INTRODUCTION

Failure to reduce greenhouse gas emissions at a rate compatible with climate stability has accelerated the search for ways of removing CO_2 from the atmosphere. Some proposed interventions involve manipulating oceans and marine ecosystems to increase, or radically enhance, their ability to absorb CO_2. "Marine carbon dioxide removal" (CDR) is a fluid category that currently encompasses a highly heterogeneous set of options, from the conservation or restoration of vegetated coastal habitats ("blue carbon"), to alterations in the chemistry of the oceans to boost CO_2 uptake (as in artificial ocean alkalinization or ocean iron fertilization). Some of these options, particularly ocean iron fertilization, have a track record of small-scale (and controversial) field experimentation, but the majority remain for the moment limited to preliminary technical assessments and ingenious modeling exercises. Methods such as artificial ocean upwelling and downwelling, or the direct capture of CO_2 from seawater, are currently grounded in speculative technological scenarios and have undergone very limited practical assessment (see Gattuso et al., 2021 for a recent review of the field).

Yet we are at an important juncture in the development of marine CDR. Recent policy initiatives suggest growing interest in creating the scientific and technical infrastructures that would make large-scale marine CDR a realistic proposition. In the United States, the National Academies of Sciences, Engineering, and Medicine is preparing a consensus report on CDR and sequestration in coastal and open ocean waters, while governments in Europe and elsewhere are funding the assessment of detailed deployment scenarios. Research consortia and philanthropic initiatives are planning pilot studies, including offshore mesocosm experiments to characterize the ecological impacts of artificial ocean alkalinization (by the European Union-funded OceanNETs consortium, for example), or the spreading of ground olivine on beaches to increase coastal carbon capture (as in the initiatives sponsored by the non-profit Project Vesta).

These initiatives have generated a lively debate over the appropriate governance mechanisms for marine CDR (McGee et al., 2018; Webb, 2020; Boettcher et al., 2021; Cox et al., 2021). While it is difficult to define principles applicable across such a diverse range of potential interventions, it is urgent that we do so. The history of ocean iron fertilization experiments has bequeathed us a very limited range of conceptual tools and governance criteria; it has also consolidated the view of marine CDR as an "oceanic" or "planetary" mode of action, paradigmatic of the fraught moral issues pertaining to "geoengineering," and best addressed through international regulatory mechanisms. While this framing has served to highlight some of the legal and ethical dimensions of the problem, it obscures the fact that marine CDR, as currently imagined, will in many and relevant ways be *site-specific*: that it represents a *localized* form of climate action, affecting coastal communities and environments most immediately, and presenting them with geographically specific balances of risks and benefits. International governance principles and national regulatory frameworks thus need to be complemented with governance processes oriented toward the place-based dimensions of these novel forms of CO_2 capture.

In what follows, I review briefly how the controversies surrounding ocean iron fertilization have shaped our understanding of marine CDR governance, tilting it toward planetary considerations. To counterbalance this emphasis, I go on to discuss the site-specific nature of proposed marine CDR methods, with a focus on artificial ocean alkalinization. In the final part of the Perspective I discuss possible ways of tackling the local governance of marine CDR, emphasizing its crucial participatory dimensions—that is, the need to establish mechanisms that would allow those constituencies most directly affected by any decision-making process to shape its outcome. National and international legal frameworks tend to devolve key decisions, such as the definition of what constitutes "legitimate scientific research" or the calculation of the relevant "environmental risks," to technical experts, and offer limited opportunities for public consultation and review. The legitimacy of marine CDR will require a more inclusive approach, however, able to tackle the local geographies at stake.

GEOENGINEERING DISTANT OCEANS

Beginning in the late 1990s, a series of ocean iron fertilization experiments crystallized initial positions on the desirability of marine CDR. Expressions of concern about the potential impact of ocean fertilization activities were issued by, among others, the United Nations General Assembly, the United Nations Conference on Sustainable Development, the Conference of the Parties to the Convention on Biological Diversity, and the Intergovernmental Oceanographic Commission of UNESCO. In 2008, the Conference of the Parties to the Convention on Biological Diversity urged national governments "to ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities, including an assessment of associated risks, and a global, transparent, and effective control and regulatory mechanism is in place for these activities" [Conference on Biological Diversity (CBD), 2008; see also Strong et al., 2009]. That same year, the London Convention and the London Protocol on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter included iron fertilization activities under the scope of its provisions (resolution LC-LP.1 2008). In 2010, the Contracting Parties to the London Convention and London Protocol adopted an "assessment framework for scientific research involving ocean fertilization" that included criteria for the definition of acceptable research activities, and the characterization of attendant environmental risks (LC 32/15, Annex 6).

In 2012, the discharge of iron sulfate and iron oxide by the Haida Salmon Restoration Corporation (HSRC) around the islands of Haida Gwaii, off the coast of British Columbia, triggered a new round of public controversy. Extrapolating from the case of ocean fertilization, the Parties to the Convention on Biological Diversity declared that "there is no single geoengineering approach that currently meets basic criteria for effectiveness, safety, and affordability, and that approaches may prove difficult to deploy or govern" [Conference on Biological Diversity (CBD), 2012]. In 2013, the contracting parties to the London Convention and the London Protocol adopted a resolution (not yet in force) to introduce an amendment "to regulate the placement of matter for ocean fertilization *and other marine geoengineering activities*" (LC 35/15, Annex 4 (my emphasis); see Webb et al., 2021 for an up-to-date discussion of international law in this area).

What is striking about these debates is the extent to which proponents and opponents alike framed the issue in planetary terms. For the proponents of these ocean fertilization activities, their goal was to assess the potential of induced phytoplankton growth "to influence the carbon budget of our planet" (Assmy et al., 2006). They sought to gather empirical data that would strengthen global models of ocean biochemistry and CO_2 uptake. For the critics, the experiments were dangerous, regardless of their scale or immediate scientific purpose, because they "give the wrong signal to the geo-engineers who would like to re-engineer our planet for profit" (ETC Group, 2009; see also Fuentes-George, 2017). Yet, by subsuming these experiments under the rubric of "geoengineering," the discussions elided crucial local dimensions. This was particularly evident in the case of the fertilization activities in Haida Gwaii. The decision by the Haida community of Old Massett to sponsor HSRC's activities in their coastal waters was driven by a host of complex considerations, including a desire to replenish depleted salmon runs and the prospect of direct financial returns through the sale of carbon credits. It also reflected a very specific experience of vulnerability to climate risk, and of neglect by national policy-makers. As Gannon and Hulme point out "when the HSRC is discursively situated within local histories and geographies of (post)colonial indigenous subjugation, resource extraction and Haida battles to restore political autonomy, it is easy to understand how this proposal gained traction within Old Massett" (Gannon and Hulme, 2018, p. 2). Once the debate was framed as a matter of "geoengineering," however, these "local histories and geographies" became peripheral. Actors with global reach and purposes—scientific consortia, environmental campaign organizations, international policy-makers—moved to center stage, while constituencies whose interests and concerns were oriented primarily to their specific socio-ecological context were marginalized (see Buck, 2018).

MARINE CDR AS LOCALIZED INTERVENTION

The local character of marine CDR is difficult to visualize when removal practices are imagined in oceanic terms. Graphic depictions of "marine geoengineering" often revolve around lone ships discharging minerals into ocean eddies (as with ocean alkalinity enhancement or iron fertilization), or present free-floating biochemical processes presumably unfolding somewhere in the high seas (as in many illustrations of ocean upwelling and downwelling). *Localizing* marine CDR is nevertheless crucial if we want to characterize the governance challenge, as it is a necessary condition for identifying the collectives and environments that will be most directly affected by its deployment. It is also crucial for designing mechanisms capable of mitigating the place-based conflicts that are bound to emerge if any of these options is used at scale.

The local nature of marine CDR is most obvious in the case of "blue carbon" strategies, which involve the conservation or restoration of vegetated coastal habitats with high rates of carbon sequestration (e.g., seagrass meadows, mangrove forests, tidal marshes). These strategies are by definition site-specific, and tend to build on existing marine and coastal conservation efforts. While it is difficult to argue *a priori* against any attempt to protect coastal ecosystems, the history of marine conservation suggests the difficulty of anticipating the full range of social, economic, and environmental impacts at the local level. A large body of social scientific literature on marine protected areas indicates the potential for conflict with residents whose livelihoods and cultural resources are directly or indirectly impacted by conservation efforts, and the challenge of devising interventions that operate synergically (McClanahan et al., 2005; Walley, 2010; Jentoft et al., 2012; Pascual-Fernández et al., 2018; Sowman and Sunde, 2018). A recent analysis of "blue carbon" strategies in Tanzania and Mozambique suggests, for example, multiple points of friction with a wide range of subsistence activities—from the reliance on mangrove forests for fuelwood, to small-scale trawling for fish, and crustaceans in seagrass meadows (Gullström et al., 2021; see also Veitayaki et al., 2017). When placed within what Carton and colleagues call "the long history of carbon removal" (Carton et al., 2020), "blue carbon" represents a new chapter to the genealogy of contentious carbon sequestration. Of particular relevance here is what Ehrenstein calls the "metrological inclusiveness" of carbon sink geopolitics; that is, who is in a position to produce globally accepted evidence of removal and sequestration, and how the uneven distribution of this ability to generate facts shapes the political ecology of the areas tasked with locking up carbon (Ehrenstein, 2018; see also Leach et al., 2012). Rather than being seen as a self-evident public good, the design of sustainable "blue carbon" initiatives requires detailed interdisciplinary research, and a robust process of stakeholder engagement (Thomas, 2014).

Local impacts are bound to be more apparent and less nuanced in the case of ocean afforestation and large-scale seaweed cultivation. Here, fast-growing macroalgae are grown at scale to remove CO_2 from the atmosphere through photosynthesis, with the carbon then sequestered through sinking or used to generate "carbon negative" products, as in the production of bioenergy with carbon capture and storage (BECCS). While terrestrial BECCS is probably the best understood (or at least the most extensively modeled) of all proposed large-scale CDR options, we have a very limited sense of how the marine versions of this approach might impact local communities and ecosystems. The experience with farming seaweeds for biofuels and other forms of large-scale mariculture suggests a significant risk of detrimental local environmental impacts (Duarte et al., 2017). Calls to investigate the full range of consequences that BECCS might carry for specific communities are even more pertinent for marine applications of this type of climate mitigation strategy (Buck, 2019a).

The localized character of non-biological forms of marine CDR is more difficult to grasp. This is partly due to the fact that their assessment has so far relied on theoretical models and speculative scenarios that tend to be insensitive toward regional-level dynamics. Models of artificial ocean alkalinization, for example, tend to estimate the "global effectiveness" of the intervention—in terms of the total amount of CO_2 extracted from the atmosphere—and assume an even distribution of the added alkalinity across the surface layer of the world's oceans. When they look at specific oceanic regions, they conclude that the site of intervention is immaterial to the scale of CO_2 removal, provided enough alkalinity is added (Lenton et al., 2018).

Yet artificial ocean alkalinization at scale, if it ever comes to pass, will be geographically specific in ways that will matter a great deal to its governance. For one, it will require extensive land-based infrastructures for the extraction, processing, and transportation of the required materials. Ocean liming, for example, involves the mining, grinding, and calcination of limestone (plus the capture and storage of most of the resulting CO_2, if the process is to result in a net reduction of atmospheric greenhouse gases). Given that transportation will represent a significant proportion of the cost (in both monetary and carbon terms), these infrastructures are likely to be located in or near coastal areas, often in close proximity to ancillary industrial activities (Renforth and Henderson, 2017). In fact, most scenarios for ocean alkalinity enhancement capitalize on already existing industrial activities. Alkalinity enhancement through the addition of magnesium oxide derived from reject brines, for example, implies a co-location with desalination plants (Davies, 2015). The hydrochloric acid that would be generated in the process (which is defined as a hazardous material in most jurisdictions) is also likely to be stored near shore (Webb et al., 2021). The kind of coastal spreading of olivine currently being investigated by Project Vesta would be much more economical if conducted in conjunction with beach nourishment efforts, a kind of "soft" coastal engineering with significant, if poorly understood, impacts on marine environments (Staudt et al., 2021). The point here is that the infrastructures required for artificial ocean alkalinization will likely be built on top of already existing industrial operations on or near shore, potentially intensifying their local environmental impacts even if they were to contribute to a net reduction of atmospheric CO_2. It is important to keep in mind, moreover, that most scenarios for artificial ocean alkalinization anticipate decades, if not centuries, of mineral production and discharge if levels of greenhouse gas emissions remain high (Keller et al., 2014).

Comparable co-location effects are evident in early modeling of CO_2 stripping. Although some of the proposed scenarios present self-supporting, stand-alone deployments (e.g., "clusters of marine-based floating islands, on which photovoltaic cells convert sunlight into electrical energy to produce H_2 and to extract CO_2 from seawater," as in Patterson et al., 2019), the truth of the matter is that these will be, once again, coastal interventions linked to extensive land-based infrastructures, including those required for the transportation and storage of the extracted CO_2 (La Plante et al., 2021). Artificial upwelling is often depicted as an untethered process merely replicating the natural circulation of water between ocean layers (and, because it does not require deliberately adding new materials to the sea, falling outside the purview of the London Convention and the London Protocol). Yet for this type of intervention to have any discernible impact on the climate it would involve deploying millions of devices (plastic pipes, pumps, swimming platforms) across large areas of the oceans. Recent field trials reveal the significant infrastructural preconditions for this sort of "non-invasive" climate action (Fan et al., 2020).

There is, in essence, no free-floating marine CDR. Even if key operations take place relatively far from shore and "out of sight," they are unlikely to be of no concern to coastal actors and communities. Social scientific research on the public acceptability of offshore wind energy, marine oil, and gas extraction, or subsea CO_2 storage makes clear that, far from being distant activities unfolding in unpopulated spaces, these industrial activities tend to be seen as directly impacting human landscapes, often as a new chapter in long histories of local resource exploitation and environmental destruction (Firestone and Kempton, 2007; Mabon et al., 2014; Günel, 2019; see also Bertram and Merk, 2020).

DISCUSSION

Neither an "oceanic" solution nor exclusively land-based, most marine CDR will represent a new kind of *inshore* practice, a compendium of littoral climate technologies with the potential to reshape the way we relate to the seas. Linking up multiple onshore and offshore activities, the impact of marine CDR will be felt most directly in coastal environments and by nearshore communities. Basic economics suggests that these operations will tend to be co-located with already existing extractive, processing, and transportation activities, potentially exacerbating environmental strains in already vulnerable areas. Optimizing the deployment of marine CDR and characterizing its potential net environmental gain thus requires greater attention to the local and regional scale of assessment.

Yet current discussions of marine CDR governance continue to be framed in planetary terms. This is true of most scientific assessments, which adopt spatially homogeneous deployment scenarios with low regional resolution. It is also true of the legal and policy initiatives that emerged in the wake of the controversies over ocean iron fertilization, which address marine CDR as a form of geoengineering and emphasize the role of international regulatory tools in mitigating transnational risks (Buck, 2019b). While this *oceanic* understanding of marine CDR reveals key aspects of the problem at hand, it is of little help in navigating the complex place-based governance challenges that are bound to emerge at smaller geographical scales.

Most immediately, this suggests the need to think more rigorously about local participation in the assessment of marine CDR experiments. International governance mechanisms like the London Convention and the London Protocol hinge on the demarcation of "legitimate scientific research," but they leave the decision of whether any given study has the "proper scientific attributes" to national or international expert bodies (London Convention 32/15). They offer little guidance on how to design a robust participatory process that is attentive to local expectations and concerns beyond the scientific qualities of a proposed experiment. National jurisdictions possess many laws and regulations with potential applicability to experimental marine CDR activities, but the manner in which they should be applied remains uncertain (Webb, 2020), and they allow limited opportunities for local participation in the decision-making process. As a result, the scientific consortia and non-profit initiatives currently planning marine CDR experiments are essentially forced to invent their own, *ad hoc* approaches to public participation.

A participatory turn in the assessment of marine CDR experimentation must start by expanding the range of actors and factors included in these discussions, as has been argued for greenhouse gas removal technologies more generally (Forster et al., 2020). One possible way to do this would be to consider CDR proposals within existing frameworks for marine spatial planning (MSP). The key advantages of MSP is that it operates at the ecosystem level, takes into account land–sea interactions, and makes explicit the tensions—and also any potential synergies—between alternative uses of marine space. Moreover, in some jurisdictions MSP is supported by legally-binding frameworks that include explicit mandates for transparency, participation, and accountability (as in the EU Marine Spatial Planning Directive).

Incorporating marine CDR into institutionalized spatial planning processes is obviously no guarantee of good governance or of meaningful public participation; the struggle to make MSP planning a properly "public" process, not subordinated to elite interests, remains as urgent as ever (Gopnik et al., 2012; Smith, 2018; Twomey and O'Mahony, 2019). But at least MSP would embed participatory practices within a reasoned consideration of the medium-term socio-ecological impacts of marine CDR. It would visualize potential conflicts with other uses of the marine environment, and help define criteria for their co-existence.

"Blue carbon" provides an obvious starting point for such an approach, as it builds on decades of experience—good and bad—in the governance of coastal conservation areas and carbon sinks. Some regional-level "blue carbon" audits and action plans already draw on the participation of a wide range of stakeholders (Porter et al., 2020), or integrate "blue carbon" into sub-national climate strategies that sanction the involvement of a diverse set of local actors (Wedding et al., 2021; see also Duarte et al., 2017). The road is less clear for marine CDR options with a more oblique link to conservation, and were the potential for far-reaching environmental impacts is much more significant but also much more uncertain. Part of the problem here is that it is more difficult to articulate—let alone quantify—the potential benefits that might accrue at the local or regional level from any given CDR intervention. In this regard, a formal MSP process can be a useful forum to discuss the direct economic benefits that might derive from hosting particular CDR infrastructures, or the allocation of any potential monetary carbon credits associated with CO_2 removals.

In sum, tackling marine CDR as a local governance challenge will necessarily shifts the parameters of the discussion. While the oceans trigger understandings of planetary fragility and demands for the protection of the global commons, coastal environments, and the communities they support are exposed to more proximate versions of climate risk and must contend with a complex mix of demands upon marine space. Under these circumstances, the governance of marine CDR becomes a vital local matter that cannot be delegated to international agreements or expert working groups. It also becomes entangled with geographically specific imaginaries of climate action and economic development, giving marine CDR a broader range of connotations than those implicit in the concept of "geoengineering." If, as Bellamy and Geden (2019) have argued, the governance of carbon dioxide removal should be tackled "from the ground up," marine CDR governance should be understood "from the coast out," placing the interests, expectations, and concerns of coastal actors at its center.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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