International and Comparative Law Quarterly (2025), **74**, 11–25
doi:10.1017/S0020589325101127

British Institute of International and Comparative Law

FORUM

Technological Change and the Law of the Sea: The Challenge of Marine Geoengineering

Catherine Redgwell

Chichele Professor of International Law Emerita, Faculty of Law, University of Oxford, Oxford, UK
Email: catherine.redgwell@law.ox.ac.uk

Abstract

A significant impetus for the negotiation of the United Nations Convention on the Law of the Sea (UNCLOS) was the impact of new technological and scientific developments on the law of the sea. Such developments have continued apace, raising the question of how UNCLOS continues to respond to new uses of, and threats to, the oceans. This article focuses on marine geoengineering as an emerging technological response to the climate emergency and its regulation by the specialised global dumping regime of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and its Protocol within the general normative framework provided by UNCLOS. It demonstrates how responding to technological developments is hard-wired into the DNA of the law of the sea, and into UNCLOS in particular, which remains the foundation for the governance and management of new maritime technologies.

Keywords: public international law; law of the sea; United Nations Convention on the Law of the Sea; Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter; London Convention; Protocol to the London Convention; maritime technologies

1. Introduction

As the International Law Commission (ILC) recently observed, innovations in technology both pose challenges and provide opportunities for international law. It made this observation in a law of the sea context, in its consideration of the topic of the prevention and repression of piracy and armed robbery at sea, where technological innovations impact both how crimes are carried out and how piracy and armed robbery at sea are combatted.[1] This is a pattern repeated across many areas of the law of the sea in the evolution of which technological and scientific developments have played a

[1] International Law Commission (ILC), 'Report on the Work of Its Seventy-Fifth Session' (2024) UN Doc A/79/10, para 437. See also N Klein, 'Maritime Security' in DR Rothwell et al (eds), *The Oxford Handbook on the Law of the Sea* (OUP 2015) 582.

significant part.[2] Indeed, a significant impetus for the negotiation of the United Nations Convention on the Law of the Sea (UNCLOS)[3] was the impact of 'revolutionary developments in science and technology, and the influence of these forces in international law'.[4]

Historically, examples of the impact of technological developments on the law of the sea abound, from weapons technology and the 'cannon shot rule' where coastal State sovereignty extended as far as its (terrestrial-based) military force could reach,[5] to the impact of the (technology-led) industrial revolution and the quest for markets and heightened demand for raw materials reinforcing the doctrine of the freedom of the high seas.[6] Resource exploitation at sea has been another area of dynamic response to technological innovation. For living resources, the discovery first of salting,[7] and then freezing, fish for preservation enabled early distant water fishing, increasing pressure on coastal fish stocks and eventually leading to expanded maritime claims. An example is Latin American 200-nautical mile claims driven, inter alia, by resource concerns to secure protection from 'growing American fleets'.[8] Today, the deep sea fishing industry is 'supported by a battery of technological innovations including global positioning systems, multi-beam sonar, and stronger and more powerful cables and winches',[9] with the consequent increased pressure on fish stocks leading, inter alia, to enhanced regulation of fishing methods and gear.[10]

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[2] T Treves, 'Historical Development of the Law of the Sea' in Rothwell et al, ibid 1; see also PW Birnie, 'Contemporary Maritime Problems' in RP Barston and P Birnie (eds), *The Maritime Dimension* (George Allen & Unwin Ltd 1980) 169,170–71; DJ Bederman, 'The Sea' in B Fassbinder and A Peters (eds), *The Oxford Handbook of the History of International Law* (OUP 2012) 371; J Kraska, 'From the Age of Discovery to the Atomic Age: The Conflux of Marine Science, Seapower, and Oceans Governance' in HN Scheiber, J Kraska and M-S Kwon (eds), *Science, Technology, and New Challenges to Ocean Law* (Brill 2015) 32.

[3] United Nations Convention on the Law of the Sea (adopted 10 December 1982, entered into force 16 November 1994) 1833 UNTS 397 (UNCLOS). With the accession of San Marino on 19 July 2024, there are currently 170 Parties to UNCLOS.

[4] The observation of Ambassador Jens Evensen (Norway) on the conclusion of UNCLOS cited in HN Scheiber, 'Economic Uses of the Oceans and the Impact on Marine Environmental: Past Trends and Challenges Ahead' in D Vidas and PJ Schei (eds), *The World Ocean in Globalisation* (Martinus Nijhoff 2011) 65, 69.

[5] Klein (n 1) 582. See also Treves (n 2) 5, who notes uncertainty in the application of this doctrine for determining the extent of the 'fixed belt' of coastal State sovereignty, including that it would be 'subject to change in response to changes in weapons technology'. However, as Akashi points out, what was proposed was not an outer limit for the territorial sea but rather the extent of the reach of terrestrial authority: K Akashi, 'Cornelius van Bynkershoek (1673–1743)' in Fassbinder and Peters (n 2) 1111. In either case, technology was key.

[6] Anand links European receptivity to the freedom of the seas in the late eighteenth and early nineteenth centuries to 'the needs and demands of the industrial revolution': RP Anand, 'Maritime Practice in South-East Asia until 1600 AD and the Modern Law of the Sea' (1981) 30 ICLQ 440, 450. See also Bederman (n 2) 371.

[7] e.g. Basque distant water fishing for cod: M Kurlansky, *Cod: A Biography of the Fish that Changed the World* (Vintage 1997) 19.

[8] PW Birnie, 'The Law of the Sea Before and After UNCLOS I and UNCLOS II' in Barston and Birnie (n 2) 12–13. Hollick outlines several possible origins of 200-nautical mile claims, including the width of the Humboldt Current and the prevailing extent of radar technology: A Hollick, 'The Origins of 200 Mile Offshore Zones' (1977) 71 AJIL 494 n 5.

[9] RM Warner, 'Conserving Marine Biodiversity in Areas Beyond National Jurisdiction: Co-Evolution and Interaction with the Law of the Sea' in Rothwell et al (n 1) 753.

[10] See, e.g. R Churchill, V Lowe and A Sander, *The Law of the Sea* (4th edn, Manchester University Press 2022) 513; N Matz-Lück and J Fuchs, 'Marine Living Resources' in Rothwell et al (n 1) 491; R Caddell and E Molenaar (eds), *Strengthening International Fisheries Law in an Era of Changing Oceans* (Hart Publishing 2019).

A similar picture emerges with respect to non-living resources. Swiftly overcome by technological developments was the Geneva Convention on the Continental Shelf[11] with its provisions on the outer limits of the continental shelf based on the limits of exploitability 'soon seen as obsolete in light of technological progress and was radically modified in [UNCLOS]' with the latter's provisions, inter alia, for a deep seabed mining regime.[12] Relatedly, energy at sea,[13] from the exploitation of the petroleum resources of the continental shelf to renewable energy,[14] and the development of offshore transportable nuclear power plants,[15] has seen legal regulation responding to technological developments.

Beyond questions of resource access and use, a whole host of other human activities at sea are impacted by technological developments.[16] Technology-enabled monitoring, control and surveillance over a diverse range of human activities at sea for good (e.g. safety of life at sea; environmental monitoring;[17] fisheries enforcement) or for ill (e.g. criminal activities; monitoring of borders; repelling migrants)[18] is increasingly evident. And the use of 'technology-enabled ocean governance' has been highlighted for the effective implementation of area-based management tools,[19] such as high seas marine protected areas (MPAs) in the Agreement under UNCLOS on Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement) when it enters into force on 17 January 2026.[20]

Last but not least is the focus of this contribution, which is the recent emergence of marine geoengineering as a novel technological response to the current climate emergency. Marine geoengineering offers a lens through which to assess the impact of new technologies on the development of the law of the sea and how this normative framework,[21] with UNCLOS at its heart, is of continuing relevance in meeting new

[11] Convention on the Continental Shelf (adopted 29 April 1958, entered into force 10 June 1964) 499 UNTS 311.

[12] Treves (n 2) 171.

[13] See, e.g. M Gavounelli, 'Energy Installations in the Marine Environment' in J Barrett and R Barnes (eds), *Law of the Sea: UNCLOS as a Living Treaty* (British Institute of International and Comparative Law 2016) 187.

[14] See further O Woolley, 'Renewable Energy and the Law of the Sea' in J Kraska and Y-K Park (eds), *Emerging Technologies and the Law of the Sea* (CUP 2022) 35.

[15] See, e.g. E Bernini, 'Small Modular Reactors and Transportable Nuclear Power Plants' in Kraska and Park, ibid 108.

[16] See, e.g. R Long, 'Striking an Equitable Balance under the Biodiversity Agreement: The Elusive Case of New Technologies, Marine Genetic Resources and the Global South' in Kraska and Park (n 14) 64.

[17] See e.g. E Papastavridis, 'Maritime Domain Awareness Tools for the Surveillance and Enforcement of Marine Protected Areas on the High Seas' (2025) 74(Supp) ICLQ 27.

[18] In the latter context, see further A Papachristodoulou, 'The Exercise of State Power over Migrants at Sea through Technologies of Remote Control: Reconceptualizing Human Rights Jurisdiction' (2024) 73 ICLQ 937.

[19] See D Freestone et al, 'High Seas in the Cloud: The Role of Big Data and Artificial Intelligence in Support of High Seas Governance: The Sargasso Sea Pilot' (2024) 11 Frontiers in Marine Science 1427099.

[20] Agreement under UNCLOS on Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (adopted 19 June 2023, not yet in force). With the threshold of 60 ratifications successfully crossed, the Agreement will enter into force on 17 January 2026. As of 1 October 2025, there were 75 Parties to the Agreement.

[21] This is not to suggest that other treaty regimes are of no relevance, but consideration of, e.g. the climate regime and of responses under the Convention on Biological Diversity (CBD) are beyond the scope of this article. See further RC Steenkamp, *International Law and Marine Geoengineering* (Nomos 2025); C Armeni and C Redgwell, *Current Law and Regulation: The International Legal Context* (Climate Geoengineering Governance Project, Working Paper No 1, 2014).

technological challenges.[22] Section 2 will first briefly explain marine geoengineering and the current state of play; then consider the regulatory response of the specialised global dumping regime of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) and its Protocol[23] to marine geoengineering research. Section 3 considers the general regulatory framework provided by UNCLOS, and the relationship between this and the London Convention regime. Section 4 concludes by highlighting the continuing relevance of UNCLOS in providing the general legal framework for the regulation of marine geoengineering activities supplemented by, and linked with, bespoke regulation of identified marine geoengineering activities under the London Convention and Protocol.

2. Future technological changes within and beyond UNCLOS: marine geoengineering

2.1. What is marine geoengineering?

Marine geoengineering is:

> deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long-lasting or severe.[24]

It is common to divide geoengineering into two broad categories.[25] One is solar radiation management (SRM) methods, which aim to reduce the amount of solar energy absorbed by the earth's surface. In the maritime context, examples include increasing ocean albedo/reflectivity (e.g. microbubbles or foam; marine cloud brightening) and enhanced ocean alkalinity (e.g. by adding lime or carbonate minerals to the oceans). The other category comprises carbon dioxide removal (CDR) methods to remove CO_2 from the atmosphere, with marine examples including ocean fertilisation (by adding iron or macronutrients such as nitrogen and phosphates), carbon storage in the ocean (e.g. liquid CO_2 placed in the water column)

[22] See generally Kraska and Park (n 14); Schieber, Kraska and Kwom (n 2); D Vidas (ed), *Law, Technology and Science for Oceans in Globalisation* (Martinus Nijhoff 2010); R Rayfuse, 'Public International Law and the Regulation of Emerging Technologies' in R Brownsword, E Scotford and K Yeung (eds), *The Oxford Handbook of Law, Regulation and Technology* (OUP 2016) 500 (with marine geoengineering case study).

[23] Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (adopted 29 December 1972, entered into force 30 August 1975)1046 UNTS 138 (London Convention); Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (adopted 7 November 1996, entered into force 24 March 2006) 36 ILM 7 (Protocol). The latter supersedes the former for Parties to both (Protocol art 23). There are currently 87 States Parties to the Convention and 53 Parties to the Protocol.

[24] International Maritime Organization (IMO), Resolution LP.4(8) on the Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities (18 October 2013) art 5*bis*. While more recently referred to as 'interventions for climate change mitigation, previously known as marine engineering', this article will adopt the term 'marine geoengineering' throughout.

[25] See, e.g. one of the first in-depth multidisciplinary studies of geoengineering; *Geoengineering the Climate: Science, Governance and Uncertainty* (The Royal Society 2009).

and ocean pumping (e.g. artificial upwelling). The fundamental difference between them is that SRM methods address the symptoms (global heating) while CDR aims to provide a 'cure' (reduce CO_2 concentration in the atmosphere).

The first assessment of the wide range of proposed marine geoengineering activities was published in 2019 and catalogues 27 approaches in total (including variations of approaches).[26] The report highlights the 'wide range of knowledge gaps which currently exist, ranging from testing of underlying principles, side effects, to practical challenges and uncertainties for upscaling', concluding that for none of the approaches identified was there adequate information to permit robust scientific assessment, much less for comparison with other approaches to climate intervention. Nor has there been extensive research on the potential interactions between the various marine geoengineering techniques.[27]

While the picture is not a static one, so far dedicated field studies have been conducted for only one marine geoengineering technique: ocean fertilisation.[28] Regulation of marine geoengineering was kick-started by a proposed commercial ocean fertilisation project by Planktos Inc. off the Galapagos Islands, which prompted expressions of concern[29] and ultimately legislative response by the London Convention and Protocol, discussed further in Section 2.2. While ocean fertilisation may have the potential to reduce the amount of CO_2 in the atmosphere, thereby contributing to the mitigation of climate change, it may also have significant adverse effects on the marine environment since many of the proposed techniques involve the deposit of substances in the ocean.[30] Scale is also problematic, with difficulty in drawing a firm line between research (especially large-scale field trials) and deployment, as is the potential for dual use (commercial/research), as highlighted by the Planktos example.

Nonetheless, recourse to geoengineering may be necessary in order to meet the temperature goal set forth in the Paris Agreement (PA) in 2015.[31] As early as 2007, the

[26] See generally PW Boyd and CMG Vivian (eds), 'High Level Review of a Wide Range of Proposed Marine Geoengineering Techniques' (IMO, Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), Working Group 41, Report No 98, 2019) (GESAMP Report) 11.

[27] ibid 23–28.

[28] Other techniques are on the cusp in a rapidly developing field, e.g. recent permitting of an ocean alkalinity enhancement project by the United States (US) (a London Convention State Party): see US Environmental Protection Agency, Permit granted under the Marine Protection, Research and Sanctuaries Act (1 June 2025) to Woods Hole Oceanographic Institution for a study of an ocean alkalinity enhancement technique approximately 38 miles northeast of Cape Cod, Massachusetts (Permit No EPA-HQ-MPRSA-2024-002). Information on ongoing activities by private and public actors is available from discussions under the London Convention and Protocol: see, e.g. information provided from the Canadian, US and German delegations in IMO, 'Report of the Forty-Sixth Consultative Meeting and the Nineteenth Meeting of the Contracting Parties LC 46/17' (22 November 2024) para 5.9.

[29] London Convention and Protocol Scientific Groups, 'Statement of Concern regarding Iron Fertilization of the Oceans to Sequester CO_2' (13 July 2007) IMO Doc LC-LP.1/Circ.14, a concern echoed by the parties to the CBD (e.g. Conference of the Parties to the CBD, Decision IX/16 on Biodiversity and Climate Change (9 October 2008) UN Doc UNEP/CBD/COP/DEC/IX/16) and in the UN General Assembly (e.g. UNGA Res 62/215 (14 March 2008) UN Doc A/RES/62/215, para 98).

[30] A Proelss, 'Law of the Sea and Geoengineering' in N Matz-Lück, Ø Jensen and E Johansen (eds), *The Law of the Sea Normative Context and Interactions with Other Legal Regimes* (Routledge 2022) 93, 103.

[31] Paris Agreement (adopted 12 December 2015, entered into force 4 November 2016) 3156 UNTS 79, art 2(1)(a). See, e.g. IPCC, 'Global Warming of 1.5°C, Summary for Policymakers' (IPCC, 2018) 19; UN Environment Program (UNEP), 'UNEP Emissions Gap Report 2017' (2017) 65; GESAMP Report (n 26) 19.

Intergovernmental Panel on Climate Change (IPCC) identified potential mitigation measures including 'geoengineering options, such as ocean fertilisation to remove CO_2 directly from the atmosphere' whilst also noting that such methods remain 'largely speculative and unproven, and with the risk of unknown side-effects'.[32] The need for caution is underscored in some of the written statements submitted to ITLOS in the context of its recent Advisory Opinion on *Climate Change and International Law* (CCAO), which refer briefly[33] to geoengineering and emphasise the need for a precautionary approach in using emerging technologies.[34] These reflect the widespread agreement which exists on the need to apply a precautionary approach in addressing emerging marine geoengineering technologies in ocean governance and decision-making,[35] with precaution a key principle under the London Convention and Protocol[36] and reflected in UNCLOS.[37] It is to these instruments that this article now turns.

2.2. Marine geoengineering under the London Convention and Protocol

The London Convention and Protocol[38] establish a global regime prohibiting dumping and the placement of matter that is contrary to the aims of the treaties. While the Convention adopts a 'permitted unless prohibited' approach, the Protocol adopts a more stringent 'prohibited unless permitted' reverse listing approach with only those (few) substances listed in Annex 1 permitted to be dumped or placed at sea.[39] For the purposes of marine geoengineering, it is the 'placement of matter' which is most

[32] B Metz et al (eds), *Mitigation of Climate Change: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (CUP 2007). ITLOS has emphasised that the IPCC's reports are viewed as authoritative assessments of scientific knowledge on climate change: *Request for an Advisory Opinion Submitted by the Commission of Small Island States on Climate Change and International Law*, (Advisory Opinion) (ITLOS, 21 May 2024) (CCAO) paras 51, 208.

[33] As Steenkamp rightly observes, given the uncertainties around the technologies and the applicable legal regime(s), it is unsurprising that specific geoengineering references are few and detailed examination in the written statements of the application of specific UNCLOS provisions to geoengineering non-existent: Steenkamp (n 21) 214.

[34] CCAO (n 32). See, e.g. Written Statement of France (16 June 2023) para 117; Written Statement of the United Kingdom (16 June 2023) para 78; Written Statement of the International Union for the Conservation of Nature (16 June 2023) paras 170–184.

[35] See UNGA, 'Report of Secretary-General: Oceans and the Law of the Sea' (14 March 2023) UN Doc A/78/67, para 18, on the theme of 'New maritime technologies: challenges and opportunities'; R Bodle, 'Geoengineering and International Law: The Search for Common Legal Ground' (2013) 46 TulsaLRev 309. See generally J Peel, 'Precaution' in J Peel and L Rajamani (eds), *The Oxford Handbook of International Environmental Law* (2nd edn, OUP 2021) 306.

[36] IMO, Resolution LDC.44(14) on the Application of a Precautionary Approach in Environmental Protection within the Framework of the London Dumping Convention; Protocol (n 23) art 3(1).

[37] CCAO (n 32) para 213: 'While the precautionary approach is not explicitly referred to in the Convention, such approach is implicit in the very notion of pollution of the marine environment, which encompasses potential deleterious effects.' See also the *Responsibilities and Obligations of States with respect to Activities in the Area* (Advisory Opinion) (ITLOS, 1 February 2011) para 135. This is not to suggest that the application of the principle is necessarily straight forward: see, e.g. Proelss (n 30) 110.

[38] On their relationship, see G Hoon Hong and Y Joo Lee, 'Transitional Measures to Combine Two Global Ocean Dumping Treaties' (2015) 55 MP 47; A Birchenough and F Haag, 'The London Convention and London Protocol and Their Expanding Mandate' (2020) 34 Ocean Yearbook 255.

[39] London Convention (n 23) art 3(1)(c); Protocol (n 23) art 1(4)(2)(2).

pertinent, with its application in practice determined on a case-by-case basis.[40] This flexibility has allowed the London Convention and Protocol regime to be extended to address emerging issues concerning potential threats to the marine environment,[41] including marine geoengineering.

In response to the Planktos incident noted in Section 2.1, in 2008 the London Convention and Protocol parties confirmed in a Resolution adopted by consensus that 'the scope of the London Convention and Protocol includes ocean fertilization activities'.[42] As with any other proposed dumping or placement activity, ocean fertilisation requires licensing by the designated national authority before it may proceed. In particular, the aim is to permit 'legitimate scientific research' to be carried out, following prior assessment, and to foreclose any other ocean fertilisation activities, for example with commercial application or deployment.[43]

This was followed two years later by the adoption of an Assessment Framework for Scientific Research involving Ocean Fertilization (OFAF), requiring prior risk assessment and monitoring of activities by the competent authorities.[44] It was developed by the Scientific Groups under the London Convention and Protocol, providing States with the parameters for assessing whether a proposed ocean fertilisation activity is 'legitimate scientific research' consistent with the aims of the Convention. It includes a requirement for environmental assessment, including risk management and monitoring, and the OFAF applies regardless of the size or scale of the project (but differentiation is made as to the extent of the information required). The assessment framework is not static and indeed is currently under review to determine whether and what technical changes might be required in the light of changing scientific knowledge.[45]

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[40] While 'dumping' is defined in similar terms under the London Convention (n 23) art III(1)(a) and Protocol (n 23) art 1(4) (and UNCLOS (n 3) art 1(5)(a)), 'placement of matter for a purpose other than the mere disposal thereof' is excluded from dumping but is otherwise not defined (London Convention art III(1)(b)(ii); Protocol art 1(b)(ii); UNCLOS art 1(5)(b)(ii)).

[41] See, e.g. Birchenough and Haag (n 38); KN Scott, 'From Ocean Dumping to Marine Geoengineering: The Evolution of the London Regime' in R Rayfuse, A Jaeckel and N Klein (eds) *Research Handbook on International Marine Environmental Law* (2nd edn, Edward Elgar Publishing 2023) 240.

[42] IMO, Resolution LC-LP.1 on the Regulation of Ocean Fertilization (31 October 2008) IMO Doc LC 30/16, para 1. For analysis, see R Warner, 'Marine Snow Storms: Assessing the Environmental Risks of Ocean Fertilization' (2009) 3 Carbon and Climate Law Review 426. For a general overview of marine geoengineering developments under the London Convention and Protocol (n 23) see further IMO, *Ocean Fertilization under the LC/LP* <https://www.imo.org/en/OurWork/Environment/Pages/OceanFertilization-default.aspx>; K Brent, W Burns and J McGee, 'Governance of Marine Geoengineering' (Centre for International Governance Innovation 2019) 43.

[43] Proelss (n 30) 101 briefly considers whether it would go too far to interpret Resolution LC-LP.1 (n 42) as imposing the positive obligation to authorise experiments constituting legitimate scientific research based on interpretation 'of the LC/LP in line with the climate change regime and, on the level of domestic law, the individual right of researchers to freedom of science', an argument potentially given legs by the recent CCAO (n 32) 222, in which ITLOS interpreted UNCLOS in the light of the UNFCCC and PA and the ever increasing climate emergency.

[44] IMO, Resolution LC-LP.2 on the Assessment Framework for Scientific Research Involving Ocean Fertilization (14 October 2010) IMO Doc LC 32/15 (adopted by consensus).

[45] By the Correspondence Group on Marine Geoengineering, which was reestablished in 2024 by the Scientific Groups of the London Convention and Protocol: IMO (n 28) para 5.18. On the general development of a more holistic approach to marine geoengineering assessment, see GESAMP Report (n 26) 85.

In 2013, marine geoengineering was placed on a treaty footing with the adoption of an amendment to the Protocol[46] to regulate the placement of matter for ocean fertilisation and to provide a mechanism for the addition of other defined marine geoengineering activities to be listed in a new Annex 4. The amendments allow for legitimate scientific research to be carried out only for those geoengineering techniques listed there ('reverse listing'), subject to a permit.[47] Although currently Annex 4 lists only ocean fertilisation, other marine geoengineering techniques can be added, future-proofing this mechanism in relation to subsequent scientific and technological developments.[48] A binding General Assessment Framework is included to inform decision-making on the permit, building on the OFAF, and under which additional bespoke assessment frameworks may be developed.[49] The possibility of adding tailor-made assessments, as has been done for ocean fertilisation, reflects a 'no one size fits all' approach to geoengineering governance.[50]

Such updating is under active consideration notwithstanding that the 2013 amendment has not yet entered into force.[51] Four further techniques have been identified for priority evaluation and possible inclusion in Annex 4:[52] the carbon dioxide removal techniques of enhancing ocean alkalinity and the cultivation of macroalgae and other biomass for sequestration; and the solar radiation management techniques of microbubbles/reflective particles/material and marine cloud brightening. Strikingly, this list includes activities that do not involve the placement of matter into the sea, but which use the oceans as a location from which to undertake geoengineering activities. While the first three of these techniques are considered to meet the definition of marine geoengineering under the Protocol and thus could be considered by the States Parties for inclusion in Annex 4,[53] there is no agreement on whether SRM techniques like marine cloud brightening fall within the remit of the London Convention and Protocol, with further work ongoing.[54]

This highlights an issue at the core of the London regime, which is that the 'amendment [is] to an existing environmental protection treaty and its capacity to provide a comprehensive governance framework for marine geoengineering activities will therefore be limited by the aims, scope and membership of the

[46] Resolution LP.4(8) (n 24) annex 4, LC 35/15 (2013) art 1(5*bis*). To date only the UK, Finland, the Netherlands, Norway, Estonia and Germany have ratified the amendment, which requires two-thirds of the (currently 53) Contracting Parties to do so before it can enter into force.

[47] ibid new art 6*bis*.

[48] Annex 4, para 1(1) defines ocean fertilisation broadly as 'any activity undertaken by humans with the principal intention of stimulating primary productivity in the oceans'.

[49] ibid new Annex 5 'Assessment framework for matter that can be considered for placement under Annex 4'.

[50] See, e.g. Royal Society Report (n 25); Armeni and Redgwell (n 21).

[51] Since publication of the GESAMP Report (n 26), there have been subsequent developments. In addition to ocean alkalinity enhancement discussed in n 28, see e.g. 'proof of concept' of marine cloud brightening in the Great Barrier Reef Marine Park: IMO, 'Report of Australia to the Scientific Group of the LC/LP' (29 April 2021) IMO Doc LC/SG 44/16, para 3.11.

[52] See, e.g. UNGA (n 35) para 18: 'Four geoengineering techniques have been identified for priority evaluation. The need to apply the precautionary approach and utmost caution in the consideration of those techniques has been underscored by the parties to the [London Convention and Protocol].'

[53] IMO (n 28) para 5.11.

[54] See, e.g. comments of the UK delegation: IMO (n 28) para 5.20.1. See also Brent et al (n 42) 46.

[Protocol] itself'.[55] Furthermore important procedural issues have been raised, such as the feasibility of making 'an amendment to an amendment'[56] or whether the more appropriate course is the adoption of a (non-binding) resolution.[57] In either case, this would signal that the London Convention and Protocol will continue to regulate marine geoengineering activities that involve the dumping or placement of matter in the oceans that poses a threat to the marine environment and provide an assessment framework to guide States in their implementation of their London Convention and Protocol obligations.

However, ratification of the Protocol itself has been slow, and the rate of uptake of the amendment very sluggish.[58] Subsequent meetings of the Parties have repeatedly encouraged ratification of the 2013 amendment not least 'to enable the Contracting Parties to confront the challenges posed by global climate change, whilst regulating these activities on a precautionary basis to ensure protection of the marine environment and human health'.[59] Pending the entry into force of the amendments to the Protocol, OFAF 'should continue to determine, with utmost caution, whether a proposed ocean fertilisation activity constitutes legitimate scientific research that is not contrary to the aims of the Protocol'.[60] While not legally binding, the OFAF Resolution provides a framework to guide States' exercise of jurisdiction and control over marine geoengineering activities in fulfilment of the obligation to prevent, reduce and control pollution of the marine environment and adds content to the procedural requirement to conduct a prior environmental impact assessment and to pay due regard to other States' rights and interests within and beyond national jurisdiction. Furthermore, it provides a reference point for assessing the necessary measures to prevent, reduce and control pollution of the marine environment required under Article 194(1) UNCLOS.

2.3. Marine geoengineering under UNCLOS

The detailed rules emerging under the London regime build on UNCLOS,[61] which establishes the general regulatory framework for activities at sea, including for marine

[55] Brent et al (n 42) 45; see also Proelss (n 30) 103, who speculates that though earlier resolutions were adopted by consensus, the provisions of the 2013 amendment might now be viewed as 'too restrictive' given that 'the use of marine geoengineering is increasingly considered indispensable for achieving the climate goals of the [PA]'.

[56] Not without analogy in the law of the sea context: the Agreement relating to Part XI of UNCLOS (adopted 28 July 1994, entered into force 28 July 1996) 1836 UNTS 3, adopted prior to its entry into force, amended its terms and after its adoption, ratification, confirmation or accession to the Convention also indicated consent to be bound by the Agreement (which could be ratified separately for those States already party to UNCLOS): see further Churchill et al (n 10) 28–29.

[57] For analysis of the extent to which these LP developments reflect global experimentalist governance, see C Armeni, 'Global Experimentalist Governance, International Law and Climate Change Technologies' (2015) 64 ICLQ 875. See also Proelss (n 30) 112 (influence of treaty bodies without formal decision-making powers, e.g. COP/MOP reflects changing governance structures of international law).

[58] See n 46 for ratification status. Amongst other things, this has implications for renvoi under UNCLOS (n 3) art 210 considered further in Section 3.

[59] Most recently, the IMO (n 28) para 5.7.

[60] Resolution LP.4(8) (n 24) para 3.

[61] London Convention (n 23) art XIII. See further C Redgwell, 'From Permission to Prohibition: The 1982 Convention on the Law of the Sea and Protection of the Marine Environment' in D Freestone, R Barnes and D Ong (eds), *The Law of the Sea Progress and Prospects* (OUP 2006) 180.

geoengineering activities taking place in, or launched from, coastal States' maritime zones, on the high seas and in the Area (i.e. the seabed, ocean floor and subsoil that lies beyond the limits of national jurisdiction). The applicability of its general provisions, and which State is entitled to exercise jurisdiction, will turn on where the activity takes place (location) and how it is characterised (function), for example as marine scientific research (MSR) or as pollution of the marine environment.[62]

2.3.1. Marine scientific research

UNCLOS does not provide a definition of MSR, the substantive provisions of Part XIII being considered sufficiently clear to establish the intended meaning.[63] The ordinary meaning encompasses 'any form of scientific investigation, fundamental or applied, concerned with the marine environment, i.e. that has the marine environment as its object'.[64] Much depends on the framing of the proposed research; for example, the ultimate objective of marine geoengineering research for CDR is to develop approaches to effect large-scale removal of carbon dioxide from the atmosphere, the prospects for which requires understanding the marine environment and its response to the application of particular marine geoengineering techniques.[65] And any activity constituting 'legitimate scientific research' under the London Convention and Protocol would undoubtedly also be considered MSR under UNCLOS.[66]

In regulating MSR, Part XIII reflects the zonal approach of UNCLOS, with the rights of coastal States generally diminishing seawards from the robustness of the provisions on the territorial sea, where unauthorised MSR constitutes non-innocent passage[67] to the exclusive economic zone (EEZ), where the coastal State has exclusive jurisdiction to regulate, authorise and conduct MSR,[68] to the freedom of MSR on the high seas.[69] Any geoengineering activities carried out or authorised by the coastal State within these zones must have due regard to the rights and freedoms of other States, including navigation, and must also be consistent with their obligations under UNCLOS in

[62] See detailed analysis, inter alia, by Steenkamp (n 21); Proelss (n 30); K Scott, 'Mind the Gap: Geoengineering and the Law of the Sea' in R Beckman et al (eds), *High Seas Governance Gaps and Challenges* (Brill 2018) 34.

[63] AHA Soons, 'Marine Scientific Research Provisions in the Convention on the Law of the Sea: Issues of Interpretation' in ED Brown and RR Churchill (eds), *The UN Convention on the Law of the Sea: Impact and Implementation* (The Law of the Sea Institute 1989) 365, 366.

[64] T Stephens and DR Rothwell, 'Marine Scientific Research' in Rothwell et al (n 1) 562, adopting the definition by P Birnie, 'Law of the Sea and Ocean Resources: Implications for Marine Scientific Research' (1995) 10 IJMCL 242. For further discussion, see Churchill et al (n 10) 783–90 and, generally, *The Law of the Sea: Marine Scientific Research. A Revised Guide to the Implementation of the Relevant Provisions of the United Nations Convention on the Law of the Sea* (UN 2010).

[65] W Burns, 'Governance of Ocean-Based Carbon Dioxide Removal Research under the United Nations Convention on the Law of the Sea' (2023) 75 MeLRev 55. See also Brent et al (n 42) 19–21.

[66] Proelss (n 30) 104.

[67] UNCLOS (n 3) art 19(2)(j). In a reflection of coastal State sovereignty over the territorial sea, coastal States have the exclusive right to regulate, authorise and conduct MSR in their territorial sea (art 245).

[68] With the expectation that consent to MSR in the EEZ and on the continental shelf will normally be given (UNCLOS ibid art 246(3)).

[69] UNCLOS ibid art 87(1)(f), subject to pts VI (continental shelf) and XIII (MSR, cf art 246).

relation to marine scientific research.[70] General principles for the conduct of MSR include requirements of openness, transparency and collaboration in research and the expectation that consent for MSR 'in order to increase scientific knowledge of the marine environment for the benefit of all mankind' will not normally be refused by the coastal State (Article 246(3)). There are certain exceptions, including for present purposes refusal of consent by the coastal State for projects involving 'the introduction of harmful substances into the marine environment' (Article 246(5)(b)).

However, there are limits to the application of these MSR provisions of UNCLOS—but not of UNCLOS generally—to marine geoengineering research, relating to the object and purpose of the activity. With respect to the object of the activity, the UNCLOS MSR regime excludes research conducted at sea that does not have as its object the marine environment. SRM marine geoengineering activities such as marine cloud brightening are one example where the activity in question, though 'launched' from, for example, a ship or installation at sea, has the atmosphere as its object, not the oceans per se.[71] As has been seen in Section 2.2, this issue has also arisen regarding the application of the London Convention and Protocol amendment to this activity.

The recent ILC Draft Guidelines on the Protection of the Atmosphere address activities aimed at 'intentional large-scale modification of the atmosphere' providing that these 'should only be conducted with prudence and caution, and subject to any applicable rules of international law, including those relating to environmental impact assessment'.[72] The commentary explicitly refers to geoengineering, acknowledging that with respect to ocean-based activities 'to the extent that "ocean iron fertilization" and "ocean alkalinity enhancement" relate to questions of ocean dumping, the [London Convention and Protocol] are relevant'.[73]

This presents an 'ocean/sky' dichotomy which may be difficult to maintain if, for example, the effects ultimately impact on the marine environment. And to the extent that the marine geoengineering research activity directed to the atmosphere requires 'launch' from a vessel at sea and/or associated installations and structures, or pipelines placed there, the general provisions of UNCLOS will clearly apply within coastal State jurisdiction and regarding the exercise of jurisdiction by flag States over their vessels within and beyond national maritime zones. In the case of the latter, marine geoengineering would constitute a high seas freedom subject to the due regard requirement[74] with respect to other high seas users and activities in the Area (Article 87(2)) as well as the general requirements of UNCLOS with respect to protection of the marine environment.

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[70] Although not a party to UNCLOS, the US considers many of its provisions to reflect customary international law, including on marine scientific research: US Presidential Proclamation No 10071, 'Revision to United States Marine Scientific Research Policy' 85 Fed Reg 59165 (9 September 2020).

[71] See further A Proelss, 'International Legal Challenges concerning Marine Scientific Research in the Era of Climate Change' in Scheiber et al (n 2) 293; Stephens and Rothwell (n 64) 562.

[72] ILC, 'Draft Guidelines on the Protection of the Atmosphere, with Commentaries' (2021) UN Doc A/76/10, 33 (guideline 7). It further states that this guideline does not seek either 'to authorize or to prohibit such activities': ibid 34, para 9.

[73] ibid 33–34, paras (3), (6).

[74] See further E Fasia, 'Due Regard Obligations in the Law of the Sea Convention' (DPhil Thesis, University of Oxford, 2024) <https://ora.ox.ac.uk/objects/uuid:b2bc0db8-7568-42d5-bd27-0f66f6da03a4>.

Another limitation on the application of UNCLOS' MSR provisions is that some activities may have a dual purpose, ostensibly MSR but with intended commercial application. The approach of the London Convention and Protocol thus far in adopting a precautionary approach has been to prohibit all but (defined) 'legitimate scientific research', excluding from its scope any research with commercial applications. While the MSR provisions of UNCLOS are not so restrictive, they likewise suggest that commercial activities would not constitute MSR. However, the general provisions of UNCLOS would apply, with the result dependent, inter alia, on location.

2.3.2. General obligation to protect and preserve the marine environment

The general environmental obligations in UNCLOS apply to marine geoengineering activities, from the general obligation to protect and preserve the marine environment, which is a cross-cutting obligation applicable to all activities at sea and which imposes both positive and negative obligations,[75] and the obligation to ensure activities under their jurisdiction or control do not cause damage by pollution to other States or to areas beyond national jurisdiction,[76] to the duties to notify[77] and cooperate[78] and the requirement to conduct an environmental impact assessment.[79]

In its CCAO, ITLOS concluded that 'anthropogenic [greenhouse gas] emissions into the atmosphere constitute pollution of the marine environment within the meaning of … the Convention'.[80] CDR marine geoengineering activities may be characterised as climate change mitigation measures, combatting this form of pollution, whilst at the same time themselves posing a pollution risk to the marine environment.[81] This point was addressed directly by ITLOS where it touched only lightly[82] upon marine geoengineering in confirming the application of Articles 195 and 196 UNCLOS:

> Article 195 of the Convention requires States, in taking measures to prevent, reduce and control pollution of the marine environment, not to transfer, directly or indirectly, damage or hazards from one area to another or transform one type of pollution into another. In this context, some participants raised the issue of marine geoengineering. Marine geoengineering would be contrary to article 195 if it has the consequence of transforming one type of pollution into another. It may further be subject to article 196 of the Convention which requires States, *inter alia*, to take all measures necessary to prevent, reduce and

[75] UNCLOS (n 3) art 192. See also *South China Sea (Philippines v China)* PCA Case No 2013-19, Award (12 July 2016) para 941.

[76] UNCLOS (n 3) art 194(2).

[77] ibid art 198.

[78] ibid art 197. As ITLOS has stressed, the duty to cooperate is an integral part of the obligations under arts 192 and 194: CCAO (n 32) para 299. It is an obligation of conduct with no obligation to achieve a particular normative outcome: ibid paras 306–307.

[79] UNCLOS (n 3) art 206.

[80] CCAO (n 32) para 179, relying inter alia on the definition of 'pollution' in art 1(4); see also ICJ, *Obligations of States in Respect of Climate Change* (Advisory Opinion) (General List No 187, 23 July 2025) para 340.

[81] The written statement by France in the CCAO proceedings (n 34), in particular, highlights the dichotomous nature of geoengineering under UNCLOS with the potential to reduce pollution (by GHG emissions) through mitigation but also as a potential source of pollution itself.

[82] As did submissions by States and international organisations. For further analysis, see Steenkamp (n 21).

control marine pollution resulting from the use of technologies under their jurisdiction or control. The Tribunal is aware that marine geoengineering has been the subject of discussions and regulations in various fora, including the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matters 1972 and its 1996 Protocol, and the CBD.[83]

3. The relationship between UNCLOS and the London Convention and Protocol

As is frequently observed, the longevity—if not immortality[84]—of UNCLOS may be attributed to a number of factors, including its character as a 'living instrument'[85] intended to be capable of further evolution through a variety of mechanisms such as renvoi to generally accepted international rules and standards.[86] Part XII UNCLOS reflects its framework character and the existence of other relevant global and regional rules and standards in three ways: first, Article 197 requires cooperation on a global and regional basis in formulating rules and standards for the protection of the marine environment; second, internationally agreed rules and standards are used as a benchmark under UNCLOS, which for pollution from dumping requires national laws, regulations and measures to be 'no less effective' in preventing, reducing and controlling pollution by dumping than global rules and standards (Article 210(6)); and, third, Article 237 addresses the relationship between the framework provisions of Part XII UNCLOS and special conventions and agreements relating to protection of the marine environment—existing ('without prejudice') and future agreements (obligation of consistency)—concluded in furtherance of the general principles of UNCLOS.[87]

As ITLOS stated in its CCAO, '[t]he rules of reference contained in Part XII of the Convention and article 237 of the Convention demonstrate the openness of Part XII to other treaty regimes'.[88] And this is not only one-way traffic: just as UNCLOS depends to a large extent on external rules and standards for benchmarking of generally accepted international rules and standards (GAIRS),[89] as this article has observed, in the

[83] CCAO (n 32) para 231. Climate-related geoengineering and biodiversity have been addressed by the CBD Parties since 2008, with a continuing de facto moratorium 'with the exception of small-scale scientific research studies within coastal waters' and acknowledgement of the work of the London regime on ocean fertilisation: see, e.g. CBD Decision IX/16 (n 29) pt C.

[84] While Churchill observes that 'No treaties – and very few constitutions – last forever', he concludes that the Convention's 'flexible and often framework nature … means that [it] should endure as the pre-eminent source of the law of the sea for many years to come': R Churchill, 'The 1982 United Nations Convention on the Law of the Sea' in Rothwell et al (n 1) 24, 45.

[85] See also R Lewis, 'The "Constitution for the Oceans"? The Law of the Sea Convention as a Living Treaty' (2025) 74 ICLQ 1; R Barnes, 'The Continued Vitality of UNCLOS' in Barrett and Barnes (n 13) 459.

[86] A Boyle, 'Further Development of the 1982 Convention on the Law of the Sea: Mechanisms for Change' (2005) 54 ICLQ 584; I Buga, 'Between Stability and Change in the Law of the Sea Convention Subsequent Practice, Treaty Modification, and Regime Interaction' in Rothwell et al (n 1) 46; see also Scott (n 62) 34.

[87] See further Redgwell (n 61) 181–83. See also UNCLOS (n 3) art 311.

[88] CCAO (n 32) para 134. See the detailed consideration of GAIRS in 'Final Report of the International Law Association's (ILA), Committee on Coastal State Jurisdiction relating to Marine Pollution' in ILA, 'Report of the Sixty-Ninth Conference' (2000) 31; C Redgwell, 'The Never Ending Story: The Role of GAIRS in UNCLOS Implementation in the Offshore Energy Sector' in Barrett and Barnes (n 13) 167.

[89] '[C]oordination and harmonization between the Convention and external rules are important to clarify, and to inform the meaning of, the provisions of the Convention and to ensure that the Convention serves as a living instrument': CCAO (n 32) para 130.

specialised dumping regime, external agreements rely on UNCLOS (and customary international law) for the provision of general rules on the exercise of legislative and enforcement jurisdiction.[90] This complementarity was explicitly acknowledged in the United Nations (UN) written statement submitted during the CCAO proceedings where it observed that 'States have addressed ocean fertilization and carbon capture and sequestration under the [London Convention and Protocol] … which complement the relevant provisions under [UNCLOS] … on pollution by dumping'.[91]

By becoming parties to UNCLOS, States have agreed to be bound indirectly by global rules and standards embodied in instruments to which they are not necessarily party and which change over time.[92] This is the import of Article 210(4) on pollution from dumping which explicitly notes that '[s]uch rules, standards and recommended practices and procedures shall be re-examined from time to time as necessary'. While it appears well-settled that the London Convention constitutes the relevant 'global rules' for the purposes of Article 210, the position of the Protocol is less clear. Wacht, for example, in his commentary to Article 210, notes that the global rules and standards referred to in its paragraph 6 'are primarily laid down in [the London Convention and Protocol]. Thus, these instruments set the international standard States have to respect when adopting national laws, regulations and measures pursuant to their obligation contained in Art. 210 (1) and (2)'.[93] Others argue that the slow rate of acceptances of the Protocol casts doubt on whether it may be considered a global rule for the purposes of Article 210 'until the vast majority of the Parties to the 1972 Convention have themselves accepted the newer instrument'.[94]

On either view, the amendments cannot (yet) constitute such a global rule. Nonetheless, the OFAF, exhorted to be adhered to by States Parties pending the entry into force of the amendments,[95] and which was adopted by consensus, represents a de minimis threshold for the application of the due regard balancing required in the zonal provisions of UNCLOS and in the implementation of its monitoring and prior environmental assessment obligations, and fleshes out the precautionary approach required that is reflected both in the London Convention and Protocol and in UNCLOS in its application to new technologies.[96] It also constitutes 'another reference point for assessing necessary measures' required to be taken by States Parties under Article 194(1) to prevent, reduce and control pollution of the marine environment from any source.[97]

4. Conclusion

In many respects, responses to technological developments are hard-wired into the DNA of the law of the sea in general, and into UNCLOS in particular, which 'remains

[90] London Convention (n 23) art XIII.

[91] CCAO (n 32) Written Statement of the UN (16 June 2023) para 29.

[92] And without the need to amend UNCLOS: see J Harrison, *Saving the Oceans through Law: The International Legal Framework for the Protection of the Marine Environment* (OUP 2017) 171.

[93] F Wacht, 'Article 210' in A Proelss (ed), *United Nations Convention on the Law of the Sea: A Commentary* (Beck/Hart/Nomos 2017) 1418 n 20.

[94] 'In practice, the London Convention is still the main source of global rules and standards in relation to dumping': Harrison (n 92) 110.

[95] Resolution LP.4(8) (n 24) para 3.

[96] See nn 36–37.

[97] CCAO (n 32) para 214.

the keystone for global ocean governance'.[98] As Campbell McLachlan observes, 'the impulse to find solutions that can be said to integrate subsequent developments with UNCLOS, rather than to derogate from it, is very strong'.[99] Even where activities are not contemplated under UNCLOS[100]—and marine geoengineering activities are certainly one example—its general provisions are adaptable and applicable. As the UN Secretary-General observed in a 2023 report on the law of the sea and new maritime technologies:

> As to the legal framework, and as recognized by the General Assembly, the Convention sets out the legal framework within which all activities in the oceans and seas must be carried out and, as such, continues to serve as the foundation for the governance and management of new maritime technologies. As a framework instrument, the Convention appears to be of sufficient breadth and flexibility to apply to new and emerging technologies, and this has proven true even through a period of significant technological advancement.[101]

While such innovations influence the use of the oceans, the challenges they pose continue to be met within the resilient normative framework established by UNCLOS, supplemented by additional rules or guidelines building on this framework, as is the case with the London Convention and Protocol for marine geoengineering activities. Indeed, it is not an overstatement that marine geoengineering provides a 'textbook example' of how the law of the sea continues to adapt and evolve.[102]

[98] UNGA, 'Report of the UN Secretary-General: Oceans and the Law of the Sea' (6 September 2024) UN Doc A/79/340, para 96. See also the ILC's affirmation that UNCLOS 'was the starting point for the topic and the approach of the Commission was not to alter but to work within the normative limits of the Convention': ILC (n 1) para 29.

[99] C McLachlan, *The Principle of Systemic Integration in International Law* (CUP 2024) 195. See also Barnes (n 85) 487, who observes that UNCLOS 'is part of the language and grammar of international law, and we cannot but help use it and be influenced by it'.

[100] Or, contemplated yet not fully regulated, such as offshore wind energy, the development of which is of increasing importance with the global drive to decarbonise. Woolley (n 14) 36–37 commends the prescience of UNCLOS in anticipating offshore power production in the EEZ (UNCLOS (n 3) art 56(1)(a)) yet then 'categorizes ways in which marine energy technologies are challenging the legal framework established by UNCLOS' with the need for gap-filling through, e.g. IMO resolutions and guidelines.

[101] UNGA (n 35) para 86.

[102] Scott (n 62) 56.

Cite this article: C Redgwell, 'Technological Change and the Law of the Sea: The Challenge of Marine Geoengineering' (2025) 74(Supp) ICLQ 11–25. https://doi.org/10.1017/S0020589325101127