Aquatic Conservation: Marine and Freshwater Ecosystems

WILEY

COMMENT

Marine Forests Forever—A Necessary Multilateral Program for a Fair Future

Paulo Horta[1] | Marina N. Sissini[1] | Alessandra Fonseca[2] | Alexander Turra[2] | Ana Claudia Rodrigues[1] | Leonardo Rorig[1] | José Bonomi-Barufi[1] | Paulo Pagliosa[2] | Eduardo Bastos[1] | Guido Grimaldi[1] | Carlos Eduardo Peixoto Dias[1] | Fabio Fialho[1] | Carlos Yure B. Oliveira[1] | Nadine Schubert[3] | João Silva[3] | Jorge Assis[3,4] | Lidiane Gouvea[3] | Cicero Alves-Lima[3] | Márcio A. G. Coelho[3] | Ester A. Serrão[3] | Pedro R. Frade[5] | Andres Mansilla[6] | Marcelo Soares[7] | Sergio Rossi[7,8,9] | Antonio Batista Anderson[10] | Jean-Christophe Joyeux[10] | Flávio Berchez[11] | Francisco Otero-Ferrer[12] | Jorge Luiz Rodrigues Filho[13] | Miguel Mies[14,15] | Moacyr Araujo[16,17] | Jason M. Hall-Spencer[18,19]

[1]Departamento de Botânica, Centro de Ciências Biológicas, Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil | [2]Departamento de Oceanografia, Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil | [3]Centre of Marine Sciences (CCMAR/CIMAR LA), Campus de Gambelas, Universidade do Algarve, Faro, Portugal | [4]Faculty of Bioscience and Aquaculture, Nord Universitet, Bodø, Norway | [5]Zoological Department III, Natural History Museum Vienna, Vienna, Austria | [6]Cape Horn International Center (CHIC), Universidade de Magallanes, Puerto Williams, Chile | [7]Instituto de Ciências do Mar (LABOMAR), Universidade Federal do Ceará, Fortaleza, CE, Brazil | [8]DiSTEBa, Università del Salento, Via Monteroni s/n Lecce, Italy | [9]Department of Marine Biology, Underwater Gardens International, Barcelona, Spain | [10]Departamento de Oceanografia, Universidade Federal do Espírito Santo, Vitória, ES, Brazil | [11]Departamento de Botânica, Instituto de Biociências da USP, São Paulo, SP, Brazil | [12]Biodiversity and Conservation Research Group, IU-ECOAQUA, Scientific and Technological Marine Park of the Universidad de Las Palmas de Gran Canaria, Telde, Spain | [13]Laboratório de Ecologia Aplicada e Conservação, Departamento de Engenharia de Pesca e Ciências Biológicas, Universidade Do Estado de Santa Catarina, Laguna, SC, Brazil | [14]Instituto Oceanográfico, Universidade de São Paulo, São Paulo, SP, Brazil | [15]Instituto Coral Vivo, Santa Cruz Cabrália, BA, Brazil | [16]Rede CLIMA-Brazilian Research Network on Global Climate Change, São José dos Campos, SP, Brazil | [17]Departamento de Oceanografia, Universidade Federal de Pernambuco, Recife, PE, Brazil | [18]School of Biological and Marine Sciences, University of Plymouth, Plymouth, UK | [19]Shimoda Marine Research Center, University of Tsukuba, Tsukuba, Japan

Correspondence: Paulo Horta (pauloantuneshorta@gmail.com)

Received: 19 November 2024 | **Revised:** 29 November 2024 | **Accepted:** 9 December 2024

Funding: This work is part of the RestoreSeas Project, with support of Biodiversa and Fapesc (FAB2019121000025). This work was supported by Biodiversa-Fapesc, EU-BiodivERsA BiodivRestore-253 - FCT DivRestore/0013/2020, CNPq, CAPES, CHIC/ANID FB210018, and ANID FOVI 220095 PROASA/FAPESP..

Keywords: carbon neutrality | climate change | marine conservation | marine heatwaves

1 | Introduction

Not only advances but also old addictions, setbacks, obstructions and delays are observed during COP16 (on biodiversity), COP29 (on climate change) and G20 in a year full of tragedies resulting from climate change; we need to look in the rearview mirror and plan new paths to be presented and discussed at COP30, in 2025, in the Brazilian Amazon. Worldwide temperature records show that 2023 and 2024 were the warmest in at least the last 2000 years (Esper, Torbenson, and Büntgen 2024). About 90% of the excess heat trapped by greenhouse gases and 30% of human emissions of carbon dioxide are stored in the ocean, shielding the planet from even more rapid changes in the biosphere. The recent acceleration in climate change is a threat not only to terrestrial systems but also to largely neglected marine ecosystems and their socio-biodiversity. Considering the relationship between global warming and biological extinctions (Malanoski et al. 2024), as well as the high vulnerability of marine biodiversity to these global threats (Pinsky et al. 2019), we call for the urgent need to create global and multilateral policies that are based on climate-smart ocean planning and carbon neutrality, focused on climate adaptation and mitigation strategies to

protect, restore and foster sustainable management of marine socio-ecological systems (Frazão Santos et al. 2024).

Terrestrial ecosystems have been carefully considered in scenarios of climate and environmental crises (Weltzin et al. 2003; Field et al. 2007; Frank et al. 2015; Malhi et al. 2020). Discussions about the deforestation of the Amazon, among many other tropical forests, reached the highest political levels and mobilised governments to create an international programme (*Tropical Forests Forever* - TFF; https://www.un.org/esa/forests/news/2023/12/7th-edition-quarterly-highlight/index.html) based on restoration actions and nature-based solutions for addressing climate change. The importance of forests for the planet's climate balance is unequivocal, even though CO_2 emissions by the present global economic system exceed the absorption capacity of this gas by forests and the ocean by 40% (Friedlingstein et al. 2023).

Marine forests are built by mangroves, saltmarshes, seaweeds and seagrasses, as well as benthic invertebrates, such as sponges and corals. Marine animal forests are biogenic habitats created by megabenthic fauna acting as autogenic ecosystem engineers that change the environment by creating a complex, 3-D biophysical structure and can develop in aquatic environments as water is a dense, viscous medium which allows traits such as filter feeding that are not possible on land. Marine forests are less often considered than forests on land, even though they play a central role in maintaining biodiversity and other ecosystem services that are fundamental to the sustenance of our societies and climate stability (Costanza et al. 2014; Rossi et al. 2022). The ocean is home to a rich diversity of plants, algae and animal forests; some of which have evolved over hundreds of millions of years (Legrand et al. 2024). Marine forests can be important carbon sinks, as well as sources, that affect the planet's climate resilience, and they promote marine biodiversity by providing habitat, contributing to resilience and restoration when necessary (Schubert et al. 2024). Many are the survivors of five planetary mass extinction events (Song et al. 2021) and thus have physiological mechanisms and reproductive strategies capable of overcoming climatic extremes and contributing to the resilience of the planet's life-support system. The genetic and biochemical background of these mechanisms, in many cases poorly understood, can provide fundamental information about the physiological responses and adaptive processes required to tackle global environmental changes (Skoog and Norberg 2013). The selection of climate-resilient strains of marine forest-forming species could reduce the extinction risk of several other species, considering their role in supporting diversity by providing habitat complexity and sites for shelter, feeding and reproduction for millions of eukaryotic and prokaryotic species. Marine forests have been used through the same framework used in the circumscription of marine animal forest (MAF), described by Alfred Wallace (Wallace 1869). The term was much later re-introduced, and international research and conservation communities advocated for MAF protection and integration into spatial plans regarding national policies and international directives and conventions. Some of these habitats are already included in international and regional conservation and management initiatives; for instance, warm-water coral reefs, cold-water coral reefs and gardens and sponge aggregations are all classified as vulnerable marine ecosystems and afforded conservation measures.

Despite their beauty, resilience, provision of ecosystem services and value (monetizable or not), marine forests are experiencing collapse on a global scale, and many could disappear in the face of the ongoing sixth mass extinction event (Biswas 2017; Ceballos and Ehrlich 2023). The amount and extent of global mass coral bleaching events in 2023–2024 are a strong signal of their worldwide degradation. Similar to tropical reef systems, octocoral and algal forests such as those formed by the seaweed *Sargassum* spp. in tropical environments or by kelps or red coral and gorgonians in cold/temperate regions have suffered increasingly from more frequent and intense heat waves over the last decade, causing habitat loss. Reduced fitness is made worse when warming occurs together with eutrophication, reducing marine forest habitats and their biodiversity in tropical, temperate and polar conditions (Peres et al. 2023).

Ocean warming and increased heat waves are happening alongside multiple stressors. Increased storm frequency and intensity overload wastewater treatment and land drainage systems, causing unpredictable pulses of low-salinity water contaminated with sewage, nutrients, and terrestrial sediment loads. The global stressors, fed by rising CO_2, are causing ocean acidification and deoxygenation. The ocean, with more and more dead zones, suffer from the combined impacts of local stressors, such as pollutants from land deforestation and fires, livestock, agriculture (e.g., pesticides), cities (e.g., pharmaceuticals), mining and hydrocarbon extraction activities. If this scenario was not already bad and complex enough, marine forests are also impacted by bottom-contact fishing and dredging that cause physical impacts similar to land deforestation, defaunation and profound substratum alteration by sediment resuspension.

The consequence of the cumulative and synergistic effects of these anthropogenic stressors is that these habitats are disappearing across the planet. In some areas, there has been 55% loss in coral cover (Tebbett, Connolly, and Bellwood 2023), 90% loss of macroalgal forest (Gorman et al. 2020) and 79%–84% loss in seagrass cover (Salinas et al. 2020). These losses have cascading effects that could lead to the collapse of ecosystem functioning and the services provided, as well as opening niches for pathogenic organisms, causing disease outbreaks that directly affect human society and economies. This trajectory to mass extinction in the ocean produces a deep transformation of ecosystem functioning with an unknown future seascape and global carbon budget (Penn and Deutsch 2022).

The severity and imminence of this planetary tipping point, triggered by the warming of 1.5°C–2°C and anticipated depending on the interactions of other pressures, demand urgent and multilaterally coordinated actions. In response to this scenario, we propose the creation of a 'Marine Forest Forever Program – MFFP' associated with reducing greenhouse gas emissions. This global programme should strengthen fundraising to finance coordinated actions in all United Nations member states.

Mapping and preventing negative impacts in remaining areas that still have good ecological status is urgent. Regarding the

Aichi Convention on Biological Diversity and Sustainable Developmental Goal 14.5 of the United Nations 2030 Agenda for Sustainable Development, humanity committed to including 10% of the ocean in protected areas by 2020. To date, only 6.4% of the global ocean is included in Marine Protected Areas, with limited effectiveness against fishing and pollution pressures (Costello and Ballantine 2015). However, the World Parks Congress of 2014 and the IUCN World Conservation Congress of 2016 called for fully protecting at least 30% of the global ocean (O'Leary et al. 2016), as agreed in the Kunming–Montreal Global Biodiversity Framework (GBF). Recent evidence reveals that only 2.5% of priority areas for conservation are within marine reserves, 40% of the sea is required to protect different aspects of biodiversity and 30% of IUCN Red List threatened species ranges (Jefferson et al. 2021).

Diagnosis of marine solutions should indicate the current health status, main stressors, anthropogenic threats and potential treatments or demands of intervention. Pollution must be mitigated with coastal runoff treatment or bioremediation programmes using, whenever possible, nature-based solutions to reestablish environmental suitability. Niche modelling can help identify current and future refugia and areas that must be prioritised for restoration, reforestation, refaunation and afforestation-integrated programmes (Bianchelli et al. 2023; Young et al. 2016). All these actions represent opportunities to foster scientific literacy, as well as citizen science dissemination regarding marine forests. Mangrove reforestation in all areas where these ecosystems have been degraded could promote the uptake of 671.5–688.8 Tg CO_2_eq over a 40-year period (Lamb et al. 2024). Seaweed forests have been estimated to export 10–170 Tg C $year^{-1}$ to the deep sea, where annually 4–44 Tg C could be sequestered for 100 years (Filbee-Dexter et al. 2024). Together with other marine forests, countries can help to fill the gap and remove more than the committed 3.1 to 3.5 Gt CO_2 $year^{-1}$ up to 2030.

All these actions must consider past, current and future scenarios of warming, acidification and sea-level rise to increase the effectiveness of restoration efforts (Burdett et al. 2024). Climate refugia (Morelli et al. 2020) are conservation priorities (Keppel et al. 2015), considering their partial ability to buffer climate change effects. Therefore, they require increased protection against local-scale stressors. These regions must be mapped for different foundation groups, as accomplished for kelp forests (Assis et al. 2023; Fourqurean et al. 2012). Resilient or resistant interventions achieve higher conservation value in the face of future climate changes, particularly if one considers the potential losses of abundance and genetic diversity in areas with smaller phenotypic plasticity where algae, animals and plants live closer to their upper thermal tolerance limits.

This new programme should contribute to the mitigation of climate change and local stressors on their function, considering that among marine forests, we have ecosystems with carbon storage rates up to 35 times greater than that of rainforests (Fourqurean et al. 2012) or sink up to 10 times more carbon (Blue Carbon) than tropical terrestrial formations (IUCN 2021). Marine forests are more efficient carbon stores than their land counterparts. Moreover, some are among the most extensive biomes on earth, but we still do not know how much carbon they can store in their structures and surrounding sediments (Gouvêa et al. 2024). Biodiversity enhancement, carbon storage, their role in biogeochemical cycles and other important parts played by marine forests must be valued for their present-day environmental services but recognised as a planetary system able to slow down (if preserved) or speed up (if the fossil fuel-based economy is maintained) the climate crisis.

Considering just three key ecosystem services—fisheries production, nutrient cycling and carbon removal—provided by only six major genera of forest-forming algae (the kelps:*Ecklonia*, *Laminaria*, *Lessonia*, *Macrocystis*, *Nereocystis* and *Saccharina*), their species generate potential values that vary between US$64,400 and US$147,100/ha each year. Collectively, these services generate between US$465 and US$562 billion per year on our planet (Eger et al. 2023). These values are mainly driven by fisheries production (average US$29,900, 904 Kg/Ha/year) and nitrogen removal (US$73,800, 657 Kg N/Ha/year). However, it is also estimated that kelp forests take up 4.91 megatons of carbon from the atmosphere/year, highlighting their potential as blue carbon systems for climate change mitigation (James et al. 2024). Regarding this perspective, considering goods and services from mangroves and salt marshes (Friess et al. 2020), Costanza et al. (1997) estimated the global value of recreational services (which was partially calculated from usage fees) to be US$574 billion/year (US$193,843/ha/year). Involving society, mainly the fractions more vulnerable, actions of conservation and restoration of these ecosystems, besides being ecologically regenerative, can represent an important driver in promoting socioenvironmental justice through the payment of environmental services. MFFP represents an important contribution to reaching the unconditional basic income proposal to promote transgenerational socioeconomic and environmental justice foreseen in the Green New Deal discussions. This considers the inclusion of the ocean and coastal-related biodiversity and actions in calculating the Nationally Determined Contributions (NDCs) and elaborating National Biodiversity Strategies and Action Plans (NBSAP), as called by the G20 Environment and Climate Sustainability Working Group (ECSWG) ministerial declaration. Integrated into a communication and educational system, the proposal can be quickly disseminated across continents, strengthening and emancipating especially the most vulnerable fractions of our societies.

Together with the TFF programme, the Marine Forests Forever (MFF) programme must be transformed into public policies implemented on a large scale in an articulated way. So far, this proposal has been presented to the Brazilian Ministry of the Environment, where it is being analysed. If the Brazilian government endorses the proposal, it must be broadly discussed during 2025 and formally presented to the United Nations during COP30. To sustain financial support for this proposal, this debate should consider other multilateral bodies, such as the G20, Organization of American States (OAS), European Union and BRICS (intergovernmental organization comprising nine countries – Brazil, Russia, India, China, South Africa, Iran, Egypt, Ethiopia, and the United Arab Emirates), to create international engagement to qualify the diplomatic and political environment for its presentation during COP30 and successful implementation up to 2026. This initiative will also give impetus and expand the impacts of initiatives such as the Kelp Forest Challenge (Eger et al. 2024), while helping to overcome

the challenges of the United Nations Decade of Ocean Sciences for Sustainable Development. This challenge is a collaborative initiative where different sectors working together can increase funding, increase awareness to protect 3 million ha and restore 1 million ha of kelp forests by 2040. Therefore, receiving the financial support of U$ 250 billion annually, a value that, if added to the expectation to support the TFF programme, coastal management, and the 2030 agenda will gain important allies. These proposals may represent an alternative and important way of implementing the Global Biodiversity Framework (GBF), as well as the loss and damage funds already under discussion at the last Climate Conferences. Academics and representatives from different institutions and countries present this programme to foster additional and necessary foundations for a regenerative and distributive economy, contributing to the strengthening of fairer societies for us humans and all forms of life. These forests store evolutionary learning that qualifies them as survivors of great mass extinctions. If they survived once, they could help us survive the challenges of the planetary crises today and forever.

Acknowledgements

This work was supported by Biodiversa-Fapesc (Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina, FAB2019121000025), EU-BiodivERsA BiodivRestore-253 - FCT DivRestore/0013/2020, CNPq, CAPES, CHIC/ANID FB210018, and ANID FOVI 220095 PROASA/FAPESP. This work contributes to the Scientific Committee on Oceanic Research Changing Oceans Biological Systems project (OCE-1840868).

Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The authors have nothing to report.

Permission to Reproduce Material From Other Sources

We are not reproducing material from other sources.

References

Assis, J., F. Alberto, E. C. Macaya, et al. 2023. "Past Climate-Driven Range Shifts Structuring Intraspecific Biodiversity Levels of the Giant Kelp (*Macrocystis pyrifera*) at Global Scales." *Scientific Reports* 13 (1): 12046. https://doi.org/10.1038/s41598-023-38944-7.

Bianchelli, S., S. Fraschetti, F. Martini, et al. 2023. "Macroalgal Forest Restoration: The Effect of the Foundation Species." *Frontiers in Marine Science* 10: 1213184. https://doi.org/10.3389/fmars.2023.1213184.

Biswas, H. 2017. "Global Marine Biodiversity: Loss and Conservation in the Anthropocene." *Coherence* 12: 12–20.

Burdett, H. L., R. Albright, G. L. Foster, et al. 2024. "Including Environmental and Climatic Considerations for Sustainable Coral Reef Restoration." *PLoS Biology* 22 (3): e3002542. https://doi.org/10.1371/journal.pbio.3002542.

Ceballos, G., and P. R. Ehrlich. 2023. "Mutilation of the Tree of Life via Mass Extinction of Animal Genera." *Proceedings of the National Academy of Sciences* 120 (39): e2306987120. https://doi.org/10.1073/pnas.2306987120.

Costanza, R., R. d'Arge, R. De Groot, et al. 1997. "The Value of the World's Ecosystem Services and Natural Capital." *Nature* 387 (6630): 253–260. https://doi.org/10.1038/387253a0.

Costanza, R., R. De Groot, P. Sutton, et al. 2014. "Changes in the Global Value of Ecosystem Services." *Global Environmental Change* 26: 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002.

Costello, M. J., and B. Ballantine. 2015. "Biodiversity Conservation Should Focus on No-Take Marine Reserves: 94% of Marine Protected Areas Allow Fishing." *Trends in Ecology & Evolution* 30 (9): 507–509. https://doi.org/10.1016/j.tree.2015.06.011.

Eger, A. M., N. Eddy, T. A. McHugh, et al. 2024. "State of the World's Kelp Forests." *One Earth* 7: 1927–1931. https://doi.org/10.1016/j.oneear.2024.10.008.

Eger, A. M., E. M. Marzinelli, R. Beas-Luna, et al. 2023. "The Value of Ecosystem Services in Global Marine Kelp Forests." *Nature Communications* 14 (1): 1894. https://doi.org/10.1038/s41467-023-37385-0.

Esper, J., M. Torbenson, and U. Büntgen. 2024. "2023 Summer Warmth Unparalleled Over the Past 2,000 Years." *Nature* 1-2: 94–97. https://doi.org/10.1038/s41586-024-07512-y.

Field, C. B., D. B. Lobell, H. A. Peters, and N. R. Chiariello. 2007. "Feedbacks of Terrestrial Ecosystems to Climate Change." *Annual Review of Environment and Resources* 32: 1–29. https://doi.org/10.1146/annurev.energy.32.053006.141119.

Filbee-Dexter, K., A. Pessarrodona, M. F. Pedersen, et al. 2024. "Carbon Export From Seaweed Forests to Deep Ocean Sinks." *Nature Geoscience* 17: 552–559. https://doi.org/10.1038/s41561-024-01449-7.

Fourqurean, J. W., C. M. Duarte, H. Kennedy, et al. 2012. "Seagrass Ecosystems as a Globally Significant Carbon Stock." *Nature Geoscience* 5 (7): 505–509. https://doi.org/10.1038/ngeo1477.

Frank, D., M. Reichstein, M. Bahn, et al. 2015. "Effects of Climate Extremes on the Terrestrial Carbon Cycle: Concepts, Processes and Potential Future Impacts." *Global Change Biology* 21: 2861–2880. https://doi.org/10.1111/gcb.12916.

Frazão Santos, C., T. Agardy, L. B. Crowder, et al. 2024. "Key Components of Sustainable Climate-Smart Ocean Planning." *npj Ocean Sustainability* 3 (1): 10. https://doi.org/10.1038/s44183-024-00045-x.

Friedlingstein, P., M. O'Sullivan, M. W. Jones, et al. 2023. "Global Carbon Budget 2023." *Earth System Science Data* 15 (12): 5301–5369. https://doi.org/10.5194/essd-15-5301-2023.

Friess, D. A., E. S. Yando, J. B. Alemu, et al. 2020. "Ecosystem Services and Disservices of Mangrove Forests and Salt Marshes." In *Oceanography and Marine Biology*, 35. Boca Raton: CRC Press.

Gorman, D., P. Horta, A. A. Flores, et al. 2020. "Decadal Losses of Canopy-Forming Algae Along the Warm Temperate Coastline of Brazil." *Global Change Biology* 26 (3): 1446–1457. https://doi.org/10.1111/gcb.14956.

Gouvêa, L., E. Fragkopoulou, T. Legrand, E. A. Serrão, and J. Assis. 2024. "Range map Data of Marine Ecosystem Structuring Species Under Global Climate Change." *Data in Brief* 52: 110023. https://doi.org/10.1016/j.dib.2023.110023.

IUCN. 2021. In *Manual for the Creation of Blue Carbon Projects in Europe and the Mediterranean*, edited by M. Otero, 144. Malaga.

James, K., P. I. Macreadie, H. L. Burdett, I. Davies, and N. A. Kamenos. 2024. "It's Time to Broaden What We Consider a 'Blue Carbon Ecosystem'." *Global Change Biology* 30 (5): e17261. https://doi.org/10.1111/gcb.17261.

Jefferson, T., M. J. Costello, Q. Zhao, and C. J. Lundquist. 2021. "Conserving Threatened Marine Species and Biodiversity Requires 40% Ocean Protection." *Biological Conservation* 264: 109368. https://doi.org/10.1016/j.biocon.2021.109368.

Keppel, G., K. Mokany, G. Wardell-Johnson, et al. 2015. "The Capacity of Refugia for Conservation Planning Under Climate Change." *Frontiers in Ecology and the Environment* 13 (2): 106–112. https://doi.org/10.1890/140055.

Lamb, W. F., T. Gasser, R. M. Roman-Cuesta, et al. 2024. "The Carbon Dioxide Removal gap." *Nature Climate Change* 14: 644–651. https://doi.org/10.1038/s41558-024-01984-6.

Legrand, T., E. Fragkopoulou, L. Vapillon, L. Gouvêa, E. A. Serrão, and J. Assis. 2024. "Unravelling the Role of Oceanographic Connectivity in the Distribution of Genetic Diversity of Marine Forests at the Global Scale." *Global Ecology and Biogeography* 33: e13857. https://doi.org/10.1111/geb.13857.

Malanoski, C. M., A. Farnsworth, D. J. Lunt, P. J. Valdes, and E. E. Saupe. 2024. "Climate Change Is an Important Predictor of Extinction Risk on Macroevolutionary Timescales." *Science* 383 (6687): 1130–1134. https://doi.org/10.1126/science.adj5763.

Malhi, Y., J. Franklin, N. Seddon, et al. 2020. "Climate Change and Ecosystems: Threats, Opportunities and Solutions." *Philosophical Transactions of the Royal Society B* 375: 20190104. https://doi.org/10.1098/rstb.2019.0104.

Morelli, T. L., C. W. Barrows, A. R. Ramirez, et al. 2020. "Climate-Change Refugia: Biodiversity in the Slow Lane." *Frontiers in Ecology and the Environment* 18 (5): 228–234. https://doi.org/10.1002/fee.2189.

O'Leary, B. C., M. Winther-Janson, J. M. Bainbridge, J. Aitken, J. P. Hawkins, and C. M. Roberts. 2016. "Effective Coverage Targets for Ocean Protection." *Conservation Letters* 9 (6): 398–404. https://doi.org/10.1111/conl.12247.

Penn, J. L., and C. Deutsch. 2022. "Avoiding Ocean Mass Extinction From Climate Warming." *Science* 376 (6592): 524–526. https://doi.org/10.1126/science.abe9039.

Peres, L. M. C., L. P. Gouvêa, J. Hayden, et al. 2023. "Effects of Ocean Warming and Pollution on Sargassum Forests." *Marine Environmental Research* 191: 106167. https://doi.org/10.1016/j.marenvres.2023.106167.

Pinsky, M. L., A. M. Eikeset, D. J. McCauley, J. L. Payne, and J. M. Sunday. 2019. "Greater Vulnerability to Warming of Marine Versus Terrestrial Ectotherms." *Nature* 569 (7754): 108–111. https://doi.org/10.1038/s41586-019-1132-4.

Rossi, S., L. Bramanti, P. Horta, et al. 2022. "Protecting Global Marine Animal Forests." *Science* 376 (6596): 929–929. https://doi.org/10.1126/science.abq7583.

Salinas, C., C. M. Duarte, P. S. Lavery, et al. 2020. "Seagrass Losses Since mid-20th Century Fuelled CO_2 Emissions From Soil Carbon Stocks." *Global Change Biology* 26 (9): 4772–4784. https://doi.org/10.1111/gcb.15204.

Schubert, N., F. Tuya, V. Peña, et al. 2024. ""Pink Power"—The Importance of Coralline Algal Beds in the Oceanic Carbon Cycle." *Nature Communications* 15 (1): 8282. https://doi.org/10.1038/s41467-024-52697-5.

Skoog, Å. I., and C. Norberg. 2013. "Life Support Systems." In *Human Spaceflight and Exploration*, 161–207. Berlin, Heidelberg: Springer Berlin Heidelberg.

Song, H., D. B. Kemp, L. Tian, D. Chu, H. Song, and X. Dai. 2021. "Thresholds of Temperature Change for Mass Extinctions." *Nature Communications* 12 (1): 4694. https://doi.org/10.1038/s41467-021-25019-2.

Tebbett, S. B., S. R. Connolly, and D. R. Bellwood. 2023. "Benthic Composition Changes on Coral Reefs at Global Scales." *Nature Ecology & Evolution* 7 (1): 71–81. https://doi.org/10.1038/s41559-022-01937-2.

Wallace, A. R. 1869. *Der Malayische Archipel: die Heimath des Orang-Utan und des Paradiesvogels: Reiseerlebnisse und Studien über Land und Leute*, vol. 2. Sydney: Westermann.

Weltzin, J. F., M. E. Loik, S. Schwinning, et al. 2003. "Assessing the Response of Terrestrial Ecosystems to Potential Changes in Precipitation." *Bioscience* 53: 941–952. https://doi.org/10.1641/0006-3568(2003)053[0941:ATROTE]2.0.CO;2.

Young, H. S., D. J. McCauley, M. Galetti, and R. Dirzo. 2016. "Patterns, Causes, and Consequences of Anthropocene Defaunation." *Annual Review of Ecology, Evolution, and Systematics* 47: 333–358. https://doi.org/10.1146/annurev-ecolsys-112414-054142.