POLICY BRIEF

DYNAMIC OCEANS, DYNAMIC SOLUTIONS

New multi-disciplinary approaches for marine conservation tools

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DYNAMIC OCEANS, DYNAMIC SOLUTIONS

New multi-disciplinary approaches for marine conservation tools

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FROM 21ST OCTOBER TO 1ST NOVEMBER,

We are currently falling short of meeting the 2030 marine conservation goals, but recent scientific and conceptual developments offer a unique opportunity to shift the course. By embracing these advancements in conservation strategies, we can turn the tide and effectively protect our oceans. This paper was produced in the frame of the Horizon Europe EU-funded project BIOcean5D [1], by a team of researchers from different disciplines, to contribute towards a holistic and functional approach of marine biodiversity conservation tools. With the recent and ongoing progress of marine sciences, including genomics, digital imaging, remote sensing devices and bioinformatics, it is crucial to bring these developments to the policy arena, in a format decision-makers can effectively use as tools to assess priorities for regions needing monitoring and protection. Embracing a large panoply of interdisciplinary tools, this Policy Brief paper leverages social sciences and international law knowledge to propose innovative protection directions, based on deep conceptual changes, to support realistic, fair and equitable approaches.

[1] European Commission grant agreement 101059915.

EXECUTIVE SUMMARY

This policy brief emphasizes the need to reconceptualize our understanding of the ocean to improve marine conservation policies.

The document is structured as follows: after a historical review of institutional engagements with the protection of ecosystems, in particular marine ecosystems. We describe a number of tools for future marine protection, starting with a philosophical reinterpretation of the ocean which underscores the need for incorporating temporal and dynamic aspects into ocean policies and thereby moving beyond static spatial biases to better reflect the ocean's fluid and changing nature. The conceptual discussion is followed by an empirical review of marine conservation strategies, concluding that while Marine Protected Areas are widely used, they alone are insufficient to address biodiversity loss and should be complemented by dynamic, knowledge-driven conservation strategies that consider the multiple scales and complexities of marine ecosystems. In the subsequent sections, we make methodological recommendations that should feed into policy design: Marine conservation strategy proposals must balance biodiversity restoration with the inclusion of local communities, ensuring ethical, transparent funding and governance that respects cultural and societal needs while avoiding exclusionary practices. Furthermore, functional diversity (FD) and phylogenetic diversity (PD) should be integrated into conservation efforts to enhance ecosystem resilience and functionality. By balancing immediate ecosystem services (the FD aspect) with long-term evolutionary potential of PD, policies can become more adaptive and effective. Finally, we recommend innovative methods for valuing marine ecosystem services, such as ecological-economic modeling and deliberative valuation, to address complexity and scientific as well as value uncertainty.

We then provide two positive policy proposals:

1. Dynamic, Data-Driven Marine Conservation Strategies: Leveraging advanced data analysis and machine learning to identify and protect critical plankton ecosystems and dynamic marine areas, aligning conservation efforts with the ocean's temporal and spatial variability.

2. Legal and Ethical Frameworks for Marine Ecosystem Protection: Marine ecosystems should be granted legal rights to their integrity. Data-driven models should be used to define and measure ecosystem integrity, and sustainable Intellectual Property Rights models should be developed that compensate ecosystems for resource use.

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RATIONALE

The policy brief underscores the importance of involving local communities in conservation planning, respecting cultural differences, and ensuring transparency and ethical considerations in financing schemes. By adopting these dynamic, knowledge-driven strategies, marine conservation efforts can become more effective and sustainable, addressing immediate and long-term challenges facing ocean ecosystems. Marine biodiversity, essential for global sustainability, climate regulation and providing various ecosystem services, is under increasing pressure from global and local human-induced stressors. Ocean ecosystems, being highly dynamic, are particularly responsive and vulnerable to these changes, with climate change, pollution, and habitat destruction, among others, accelerating ecosystems and biodiversity loss. While scientific evidence underscores the urgency of addressing these drivers, uncertainty remains about how best to mitigate their impacts. COP16 of biodiversity, held for the first time in Colombia, provides a platform to move beyond traditional approaches focused on mitigation and adaptation, encouraging a more integrated strategy that addresses the underlying causes of ecosystem degradation.

In this sense, the present Policy Brief is a first compilation of new tools for ocean protection, from a conceptual reinterpretation of the ocean to the evaluation of the effectiveness of current spatial marine conservation strategies, from an assessment of how we can improve them and what alternatives we can implement, to the identification of key of marine and coastal ecosystem services, from the use of environmental valuation methodologies to the recognition of the need to include balanced genetic diversity and ecosystem roles for their protection.

Additionally, within the framework of understanding the five key dimensions of the ocean, i.e., 3-dimensional space, time, and human impact, promoted by the European Union project BIOcean5D, we emphasize herein the different feasible possibilities of implementation in the international panorama, to show the importance of considering social, ethical and transparency concerns in the implementation of Marine Protected Areas, but in general of any conservation strategy, which is strictly linked to today's society.

The present document contributes to the next steps to ensure ecosystem protection, introducing the Key Ocean Planktonic Areas (KOPAS) concept as dynamic seasonal MPAs. Also, we strived to prioritize the importance of plankton as one of the major drivers for change, and we furthermore focused on analyzing marine ecosystems as subjects of law. Based on a scientifically informed understanding of the reality of our environment, we detail the need to implement more dynamic and adaptive strategies to ensure the effective protection of ecosystems. These conceptual inputs and concrete proposals are presented in the frame of current international normative frameworks and of the different existing research gaps that we intend to fill through this proposal.

INTRODUCTION

GBF and UNCDB COP16: A key milestone towards 30% of protected ocean in 2030

COP16 of UNCBD is being held for the first time in Colombia, a country renowned for its vast biodiversity and diverse ecosystems. Given its rich natural heritage, Colombia, like many other nations, faces significant challenges in conservation and the sustainable use of natural resources.

COP16 will enable leaders, scientists, and decision-makers worldwide to review the conservation goals proposed at COP15, whose targets were established in the Kunming-Montreal Global Biodiversity Framework (GBF) to halt and reverse biodiversity loss by 2030 as a primary goal.

Four key components were put forward:

- **CONSERVATION AND RESTORATION OF ECOSYSTEMS**
- **SUSTAINABLE USE**
- **EQUITABLE BENEFIT SHARING**
- **RESOURCE MOBILIZATION**

Focusing on the ocean, it is widely recognized that marine biodiversity maintains global ecological balances (e.g., carbon sequestration and climate regulation) and is at the origin of several other key ecosystem services (ES) of regulation, support, provisioning, and culture, which are deeply linked to the health of human societies. We now know that marine biodiversity and ecosystems, which evolve in a fluid and highly dynamic environment, change more rapidly than terrestrial ecosystems[2], and additionally that they are affected by the cumulative effects of global (ocean warming, deoxygenation, acidification, drying) and local (pollutants, exploitation of natural resources, expansion of the oceans) anthropogenic stress factors[3]).

There is sufficient scientific evidence showing that the impacts of the direct and indirect drivers of global change have accelerated, with land and sea use change, direct exploitation of organisms, climate change, pollution, and the increase of invasive species being the major causes of ecosystem and biodiversity impacts[4].

However, there is significant uncertainty about mitigating the negative impacts we are witnessing now and in the forthcoming years. It is crucial to address mitigation and adaptation, commonly discussed at climate change conferences and the reduction of global drivers of ecosystems and biodiversity loss. This integrated approach is expected to ensure the conservation and resilience of ecosystems, maintaining their essential functions, services, and contributions to human well-being.

To conserve marine ecosystems and natural marine resources, in a context in which **only 3 percent of the ocean is considered free from human pressure, strategies must be created to better dimension and understand the ocean's and marine ecosystems' complexity to protect them.**

The present Policy Brief offers a compilation of science-based strategies for future ocean conservation tools. It aims to show the importance of understanding the ocean, its ecosystems, and its biodiversity from different points of view and to propose innovative and dynamic conservation strategies based on international legal frameworks. To improve existing conservation mechanisms, we acknowledge the importance of the essential

[2] Blowes et al., 2019
[3] Halpern et al., 2015
[4] IPBES, 2019a

components of the ocean, its fluidity, and its dynamic nature, as well as the key role of an understanding of human factors.

Assuming COP16 is to be a milestone both in the promotion of strategies that contribute to meeting the goals set for 2050 in the GBF, the revision of the EBSAs (Ecological and biological significant areas), and in the assessment of compliance measures towards effective 30% protection by 2030, is completely necessary. These strategies should not only focus on a geographical indicator (regarding how much area in km² is protected) but must also prioritize their effectiveness in protecting ecosystems.

Historic and Scientific Context

Threats to global biodiversity and the rise of awareness

It is now well known that global biodiversity is threatened by different factors, most related to anthropic activities that originated during the first Industrial Revolution. Since then, the consumption of natural resources, and therefore the environmental pollution, increased, all the more so as it was associated with little knowledge about the negative impacts of mass production and a lack of strategies to minimize pollution. Over the years, the impacts associated with pollution have become more evident, which has led to increased environmental, social, and economic awareness and responsibility and fostered the adoption of international conventions, treaties, and agreements throughout the world, which attempt to protect nature.

Evidence raised by IPBES

According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), in most parts of the world, nature has been considerably altered by human factors, resulting in rapid deterioration. Over the last 50 years, the direct and indirect drivers of global change have accelerated, with land and sea use change, direct exploitation of organisms, climate change, pollution, and the spreading of invasive species, which are significant causes of ecosystem and biodiversity impacts [5]. In this regard, it is currently estimated that 75% of the land surface has been significantly altered, while 66% of the ocean surface is experiencing increasing cumulative effects, and more than 85% of the wetland area has been lost.

Regarding the impact on ecosystems, the latest IPBES report [6] estimates that global ecosystems have shown an average decline of 47% compared to their estimated natural baselines. In terms of marine ecosystems, more than 40% of the ocean surface had been significantly affected by 2008, a situation that worsened in 2014 when it was estimated that 66% of the ocean was experiencing increasing cumulative impacts. Also, as of the year 2014, this same report described that only 3% of the oceans were free from human pressure, with the destruction of ecosystems such as seagrass beds and coral reefs, rising water temperatures, ocean acidification and pollution being the major causes of the loss of marine biodiversity.

Climate Change and Biodiversity Loss

Climate change is one of the most impactful causes of ecosystemic and biodiversity loss. According to the Intergovernmental Panel On Climate Change (IPCC), since 1970, the global ocean has warmed, and the rate of ocean warming has more than doubled since 1993. Marine heatwaves have significantly increased in the last few years, becoming more intense and extensive. These cumulative factors have forced many marine species (as monitored since 1950) across various groups to undergo shifts in geographical range and seasonal activities in response to ocean warming, sea ice change, and biogeochemical changes, such as oxygen loss [7].

Habitats and Species based assessments: knowledge gaps

In terms of biodiversity, affected by the massive loss of ecosystems and, therefore, of natural habitats, the Living Planet Index [8] shows an average 69% decrease in relative abundance of monitored wildlife populations between 1970 and 2018 based on 32.000 species of mammals, birds, fish, reptiles and amphibians around the world. In terms of marine biodiversity and its trends, although estimates of species count differ among

[5] IPBES, 2019a
[6] IPBES, 2019b
[7] Pörtner et al., 2021
[8] WWF, 2022

methodologies, it is reckoned that of the total number of species that exist, between 11 and 78% have been discovered and described, which points to a great lack of knowledge of global marine biodiversity. Providing figures on the total loss of biodiversity is a current research topic.

However, based on the known and described species, there have been several documented human-caused marine species extinctions, as well as evidence of the reduction of biodiversity in terms of abundance due to the reduction of the maximum potential catch as a result of the overfishing [9] among other factors. It is known that marine ecosystems and the different species that inhabit them will be strongly impacted by climate change [10]. Thus, for specific marine ecosystems, such as coral reefs, it's clear that the ecosystem's capacity to adapt and, therefore, its resilience to warming and acidification of the waters is diminishing.

Emergence of Protection Measures and Tools

Against this backdrop and taking up the origins of environmental concerns that led to a wide range of conventions and allowed the creation of international commitments, the design and implementation of protected areas emerged and was consolidated as a strategy for ecosystem and biodiversity conservation. The concept has its roots in the creation of the first national natural parks and wildlife sanctuaries, places where specific zones were delimited to preserve natural resources, especially for the conservation of certain species and biodiversity at large [11]. Initially, regional conservation strategies focused on small territories. Still, they gradually became integral to an international environmental agenda as part of the actions developed to deal with the adverse negative effects of human activities.

RAMSAR (1971), WHC (1972), CMS (1979)

After several endeavors, a first institutional step ensued through the Ramsar Convention, formally known as the Convention on Wetlands of International Importance, held in 1971. This convention aimed at providing a framework for the conservation and wise use of wetlands and their resources. Ramsar included marine areas where the depth at low tide is not greater than 6 meters [12].

The World Heritage Convention (WHC), held in 1972, for the first time acknowledged internationally the importance of preserving the cultural heritage of humankind. The convention recognizes three main conservation values, natural, cultural, or mixed, but in environmental aspects the convention presents an opportunity to protect ecosystems displaying important cultural and socio-economic interactions.

In 1979, the Convention on the Conservation of Migratory Species of Wild Animals (CMS) established itself as one of the pillars of biodiversity conservation focused on migratory species [13].

UNCLOS (1982)

In 1982, independently of the international conventions on the environment, the United Nations Convention on the Law of the Sea (UNCLOS) was adopted, introducing Exclusive Economic Zones (EEZ) and the definition of pollution of the marine environment, a term related to the activities that are/ are not allowed to be carried out in the sea [14]. In UNCLOS, the conservation of living marine resources is differentiated in the EEZ (article 61) and in the high seas (article 119). In both cases, conservation is mainly tied to the possibility of fishing activities that do not induce the deterioration of marine ecosystems and avoid overexploitation. However, the Convention does not provide a specific framework or tool for the protection of the marine environment; on the contrary, due to the complexity of creating a maritime safety regime, there are important limitations on the convention and its enforceability at the local level, where independent interpretations have generated great discussions on its effectiveness.

CBD: From Rio-92 to GBF targets: The consolidation of protected areas

In the absence of instruments aimed directly at protecting ecosystems and global biodiversity in general, during the United Nations Conference on Environment and Development (the Rio "Earth Summit"), the Convention on Biological Diversity - CBD was opened for signature in 1992 [15].
For the first time, a protected area was defined

[9] IPCC, 2022
[10] Calvin et al., 2023
[11] Lausche & Burhenne-Guilmin, 2011
[12] Ramsar Convention Secretariat, 2016
[13] United Nations, 1979
[14] UN General Assembly, 1982
[15] Secretariat of the Convention on Biological Diversity, 2001

as **"a geographically defined area which is designated or regulated and managed to achieve specific conservation objectives"**[16].

Since its establishment, 14 ordinary meetings of the Conference of the Parties (COP) have been held. The most recent was COP 15, held between China and Canada, leaving as a precedent the Kunming-Montreal Global Biodiversity Framework (GBF), which is divided into four main goals and 23 targets to be achieved by the year 2050. The GBF is one of the most ambitious international agreements to date.

THE GBF FOUR MAIN GOALS[17]:

1. PROTECTION AND RESTORATION

through the integrity, connectivity, and resilience of all ecosystems by substantially increasing natural areas, halting human-induced species extinction, and safeguarding genetic diversity.

2. PROSPER WITH NATURE

through the sustainable use and management of natural resources, including assessing, maintaining, and enhancing nature's contributions to people, including ecosystem functions and services.

3. FAIR AND EQUITABLE

sharing of monetary and non-monetary benefits from utilizing genetic resources, digital information sequences, and traditional knowledge, including indigenous and local communities.

4. INVESTMENT AND COLLABORATION

including financial resources, capacity building, and scientific and technical cooperation, that are necessary for the proper implementation of the GBF in a way that is accessible to all parties, especially developing countries.

Specificities of Marine Protection and the role of BBNJ

Recently, in December 2022, on the date on which the GBF was adopted, objective A was introduced, highlighting target 3, on Protected Areas (PAs) or Other Effective Area-based Conservation Measures (OECMs), better known as "Paris target for biodiversity". The GBF underscores the importance of ensure and enable that by 2030 at least 30 percent of terrestrial, inland water, and coastal and marine areas, prioritizing areas of particular importance for biodiversity and ecosystem functions and services, are conserved and effectively managed through ecologically representative, well-connected and equitably governed systems[18].

Today, the percentage of Marine Protected Areas (MPAs) at the global level has slowly increased, covering approximately 8.17% of the marine environment[19], building from a 2010 baseline of 1.17%. Additionally, considering the geopolitical division of the ocean, 18.7% of national waters are under some protection scheme, e.g. an internationally recognized marine conservation alternative or only a local one. In contrast, only 1.44% of the high seas are protected, considering the high seas represent 64% of the global ocean. The situation is not encouraging in view of the proposed goal for the year 2030[20] and for which, although there is not much clarity in the implementation of offshore PA, the newly negotiated Biodiversity Beyond National Jurisdiction (BBNJ) provides for the first time coordination of conservation measures for areas outside Parties' Exclusive Economic Zones (EEZs), and includes a mechanism to delineate and establish MPAs.

Interim conclusion: concerns about effectiveness

The effectiveness of the CBD has been the subject of discussion and research since a general problem with international conventions is the difficulty of adapting international regulations locally. Although the Convention has consistently moved forward, several goals still need to be met, particularly related to protecting 30% of the world's ecosystems. Some of the main challenges facing protected areas in the CBD framework are the social conflicts around protected areas, the sharing of benefits, the increasing rate of degradation of biodiversity and

[16] United Nations, 1992
[17] Secretariat of the Convention on Biological Diversity, 2023
[18] Secretariat of the Convention on Biological Diversity, 2023
[19] UNEP-WCMC et al., 2023
[20] Secretariat of the Convention on Biological Diversity, 2022

ecosystem services, the lack of sectoral integration, and the increasing economic power of transnational corporations [21].

These concerns, which are focused on more than just the CBD or the BBNJ treaty, have been raised several times and contribute to the uncertainty about the effectiveness of MPAs. There is, in particular, great concern that the goal of protection is focused solely on defining and covering a geographic area rather than on guaranteeing the adequate state of marine ecosystems. This concern will be addressed in the following section of this Policy Brief.

A conceptual reinterpretation of the ocean underscores the need to incorporate temporal and dynamic aspects into ocean policies and moving beyond static spatial biases to better reflect the ocean's fluid and changing nature. The conceptual discussion is followed by an empirical review of marine conservation strategies, concluding that while Marine Protected Areas are widely used, they alone are insufficient to address biodiversity loss and should be complemented by dynamic, knowledge-driven conservation strategies that consider the multiple scales and complexities of marine ecosystems.

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[21] Chandra & Idrisova, 2011

NEW TOOLS FOR FUTURE MARINE PROTECTION

Reinterpretation of the oceans: deep conceptualizations and their evolution

Policies directed towards the ocean (and, in particular, towards ocean protection) embody deep conceptualizations of the ocean itself. Acting on the conceptualization, through engineering and negotiation is thus a way to accompany transitions, for instance by pointing out conflicting conceptualizations, or testing new concepts [22]. The ocean constitutes indeed an interesting case study for conceptual negotiation and reconceptualization, given its otherness, of the current pressure exerted by anthropic activities on many aspects of oceanic status and life, of emerging knowledge about its physical and biological nature, and in particular in view of the need to look for and plan ahead actions on a long time span, measured not in decades, but in centuries and millennia. Focusing specifically on the ocean, the UNESCO's "One Planet, One Ocean" initiative intimates that "we need to change the way we *think* and act" [23]. In particular, some aspects of existing conceptualization of the ocean and of marine life appear to hinge on a spatial bias, and to neglect temporal and dynamic parameters that are more in line with recent scientific advances. It is a main tenet of the current Policy Brief that temporal and dynamic aspects should be leveraged in future protection tools.

Existing conceptualizations of the ocean and marine life are diverse and at times inconsistent

The ocean is at present legally conceptualized in many different, at times mutually inconsistent ways: as a *resource*, as a set of *resources*, or as a *means to circulate resources*. It is further conceived in terms of a *vast divisible territory* over which different levels of national sovereignty and international cooperation can be exerted [24]. The focus on legal regulations of *resource extraction* and on *territorial rights* stem from two main concerns driving the standard legal conceptualization of oceans: wealth and power, economics and politics.

More generally, existing conceptualizations may be inadequate or partial and enter into mutual conceptual conflict. The sea has been conceptualized both as an *inexhaustible resource* but also as a *limited resource*, whereby it is rational to protect it through territorialization; as an *alien space* but also as a much desired background of personal development and well-being [25] or alternatively, as an entity to be *superseded* [26] and *mentally canceled*; as a *connector*, whereby it must be free from enclosures [27] to allow free movement on its surface, but also as a *frontier*, whereby it must be policed; as *purely material body of water* but also as a *living entity*, even as an *ancestor*, the latter characterization promoting an intriguing synergy between some ancient narratives of the origin of humans, and recent scientific, Darwinian theorizing [28].

Conceptualizations are culture-sensitive

Conceptualizations are culture-sensitive. A survey by Sugimoto et al. (2021), on the perception and values attached to the Ocean on Okinawan islands, shows that resources provided by the sea are considered locally as *lavish gifts*: the ocean is bountiful, and this perception of obtained sea-food as marine gifts, makes it difficult to cognitively accept the relevance of a purely quantitative nature of *economic services* the ocean and its inhabitants would provide. Services and gifts–in terms of the type of measures they involve–enter into mutual conflict. Another salient dimension tested through the Okinawa survey is the "fear and respect for nature" dimension. Typhoons, in particular, are feared, but they are given a positive valence by Okinawan islanders, as *purificatory events*, necessary for the good health of the ocean.

[22] Casati et al. forthcoming
[23] UNESCO, 2013
[24] Nordquist et al., 2018
[25] Nichols, 2015
[26] Connery, 2006
[27] Grotius, 2012
[28] Hermitte, 2011

Conceptualizations evolve

Ever deeper hesitations testify to the fact that concepts evolve [29], and if differences are sometimes easy to locate, they turn out to be particularly hard to reconcile. The ocean can be thought of as a *space* (i.e., as per the 1982 Montego Bay Convention) but also as the *content* of that space; as a *physical system* but also as a *biological system*; as being a surface or pair of surfaces (sea/air surface and sea bottom) but also as being a *vertically* organized space, i.e., as having an irreducible *depth* [30]. "Linnaean" categorizations still lurk in the taxonomies of the different "seas" and "oceans" of the world, and contrast starkly with the unitary, *one-ocean conception* nowadays heralded by bio-physical researchers and climatologists.

Conceptualizations can be improved upon

Alternate conceptual representations proposed in the biological and geophysical literature include the notion of *unity and indivisibility of the ocean*, both spatially and in terms of internal dynamics [31]. Unity-focused reconceptualizations create a framework that is hospitable to more sensitive policies and legal instruments, such as the management of commons and the attribution of legal personality to the ocean.

Spatial biases modulate current ocean representations

That different perspectives are alive and kicking in the negotiations about the sea can be gathered from the variety of existing policies and attitudes. Steinberg (2001) distinguished between three approaches to sea control: *laissez-faire*, exemplified by the principle of the freedom of the sea for all; *territorialization*, furthering coastal states' control into adjacent marine areas; and *stewardship*, a form of limited control to protect maritime interests without fully embracing territorialization.
These conceptualizations compete for embodying the mercantile, navigational and military vision of the ocean respectively, born of the era of European route openings and subsequent colonization. *The protection of marine areas is at times synergistic with economic interests about their content, at times antagonistic*. The assessment of MPAs' economic consequences crucially depends on how costs and benefits are defined and measured.

Importantly, suppose biological benefits such as habitat protection and ecosystem resilience and non-market values to humans which originate from caring for marine life are appreciated economically. In that case, economic assessments may turn out very differently than if one only compares opportunity costs of protection and management costs with an increased abundance of commercially valuable fish elsewhere.

Appropriation is a common solution, mostly based on land-projected areas (territorial waters, Exclusive Economic Zones), as if drawing lines on a map was a cognition-friendly, always at hand solution. Marine protected areas (MPAs) further the territorialization of the sea in the name of environmental protection. However, it is questionable whether in general territorialization can efficiently cope with the extreme mobility of currents and the sea biome (e.g., the benefits of spill-over effects on ocean ecosystems are still widely debated). Recognition of the biological primacy of the sea has given rise to other legal protection instruments, such as the individuation of Key Biodiversity Areas [32]. On a different path, the valuation of the ecological services of the ocean and its inhabitants is reflected in different approaches, from the *monetization* of (parts of) the ocean [33] to the management of commons, from the *labelization* of (parts of) the ocean as *common heritage*, according to the 1982 Montego Bay Convention, to the proposal of attributing legal personhood to the ocean [34], to the scheduling of moratoria in ocean exploitation.

Temporal and dynamic parameters of concepts should be leveraged

Speaking to the latter point, conceptual analysis shows that spatial conceptions of the ocean still dominate the policy discussion, and that the *temporal parameters* in ocean conceptualizations, being in general neglected, could be leveraged in future discussions. One proposal to go beyond the idea of a *space to preserve* – necessarily, this space will always end up being a *portion*, often coastal, of the sea – is to think of a different organization of *time* to succeed in investing *all the* space of the sea [35]. The lockdowns of 2020 show that it is possible, though

[29] Vosniadou, 2009
[30] Steinberg, 2017
[31] Jacques et al., 2020
[32] Abreu et al., 2019
[33] Deloitte, 2017
[34] David, 2019
[35] Casati, 2022

costly, to reorganize time, to get out of the structure of worked weeks and insert chronological blocks, temporal islands where society – *the whole* society – does things differently from what it usually does, and in a sense a-normal [36].

As far as the ocean is concerned, one could study the possibility from time to time of running a *blank year*, or just a blank month, in which our species would not go to sea, for example, already in 2030, with *compensations* for those who live from the sea. Empirical data encourages us to go in this direction. Again, during the 2020 lockdown, cetacean whales came closer to coasts, probably because they were no longer disturbed by the noise of boats; we know that during the two world wars of the 20TH CENTURY, the reduction of fishing activity allowed the fish stocks to partially recover. Instead of protecting a *limited* marine area for an *indefinite* time, one could protect the *whole* sea for a *definite* time.

Marine Conservation Strategies (MCSs): effectiveness, limits, and opportunities

The lack of knowledge of the oceans and the various challenges the oceans face have contributed to oceans' rapid deterioration

In recent years, concern about the state of the oceans has become a global issue, leading to a significant increase in our understanding of the marine environment and its various components. Despite these advances, ocean exploration continues to encounter formidable challenges. The world's oceans cover approximately 71 percent of the Earth's surface, and the five major oceans are home to 94 percent of the world's wildlife. Surprisingly, only 5 percent of this vast expanse has been systematically explored [37]. Of this 71 percent, 64 percent constitutes the high seas which may be even less known.

This lack of knowledge is compounded by the numerous challenges the oceans face. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) [38] 66% of the ocean area is undergoing an increasing number of cumulative stresses. In 2014, only 3 percent of the ocean was considered free from human pressure. Such relentless human intervention has precipitated the rapid degradation of marine ecosystems, leading to instability and resulting in a loss of biodiversity, a decrease in ecosystem services related to food provision, reduced CO_2 absorption capacity, ocean acidification, rising average temperatures, and more [39].

Marine Spatial Planning as a response for the conservation of marine ecosystems

Against this background, inspired by the conservation policies initially established for continental (land) ecosystems, various international organizations have proposed and implemented marine spatial planning (MSP) schemes, which are a strategic and comprehensive process to **"analyze and allocate the use of the sea areas to minimize conflicts between human activities and maximize benefits, while ensuring the resilience of marine ecosystems"** [40] and which include the instrument of Marine Protected Areas (MPAs), as a response to the adverse effects caused by humans.

In general, although the International Union for Conservation of Nature (IUCN) recognizes that there are different definitions of MPAs and different authors agree that the definitions vary according to the objectives of protection, the interests of the area manager, cultural values, economic activities and other factors, our study is based on characterization of an MPA as **"a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long- term conservation of nature with associated ecosystem services and cultural values"** [41].

MPAs in the framework of the CBD

After the notion of Marine Protected Areas originated in the World Congress on National Parks in 1962, a proposal came in 1976 to allow every sovereign state to establish MPAs at over 200 nautical miles, aiming to protect biodiversity, promote healthy and resilient marine ecosystems, and provide societal benefits. MPAs found their full endorsement within the framework of the Convention on Biological Diversity (CBD) in 1992. CBD defines a Protected Area and sets this tool as a central axis in the conservation and sustainable use of natural resources [42]. The notion also dovetails with Article 145 of the United Nations Convention on the Law of the Sea,

[36] Fernandez-Velasco et al., 2020
[37] Santoro, 2017
[38] Watson et al., 2019
[39] Sala et al., 2021
[40] Iglesias-Campos et al., 2021
[41] Day et al., 2019
[42] Secretariat of the Convention on Biological Diversity, 2001

where it is mentioned that the relevant authorities must adopt rules, regulations, or procedures for the marine environment [43], through (1.) prevention, reduction, and control of pollution and for (2.) protection and conservation of natural resources.

In fact, in the High Seas Treaty, also known as the Agreement on Biodiversity Beyond National Jurisdiction (BBNJ), the MPAs are defined according to the same geographic delimitation established for biodiversity conservation and with the concept of sustainable use of natural resources [44]. MPAs are also a key ingredient of the so-called Nature-Based Solutions (NBS), which use ecosystems and their services to address societal challenges. In the case of marine ecosystems, MPAs are a tool meant to address food security, human health, risk reduction, and climate change.

Are MPAs mostly paper parks?

Today, the percentage of MPAs globally has slowly increased, covering approximately 8.17 percent of the marine environment [45], starting from a 2010 percentage of 1.17. Additionally, considering the geopolitical division of the ocean, 18.7 percent of national waters are under some protection scheme, whereas only 1.44 percent of the high seas are protected. This trajectory could be more ambitious as the proposed goal for the year 2030 is to protect 30 percent of the marine environment under effective restoration [46].

Are MPAs effective for achieving sustainability goals and conserving marine ecosystems? There is a research and policy debate about the effectiveness of the MPAs. Different authors have reported that this type of instrument, besides being costly, in terms of its implementation and maintenance [47], is not effective and only creates “paper parks”, legally constituted but ineffective marine areas. For example, according to the study “*Unmanaged = Unprotected: Europe’s marine paper parks*”, Perry et al. (2020) report that in 2018, about 85 percent of EU MPAs did not have a management plan, 95 percent of the total protected areas in the Mediterranean do not have a differentiated regulation between protected and unprotected spaces, and only 5 of the 73 offshore MPAs in the UK have progressive conservation targets.

This inefficiency, which primarily stems from a lack of management, follow-up, and monitoring (Maestro et al., 2019), is reflected in the fact that the main acknowledged threats to EU MPAs include maritime traffic (66% of the MPAs), fishing (32% of the MPAs), and submarine cables (26% of the MPAs) [48]. In other words, while MPAs may have some conservation strategies in place, they still face significant anthropic pressures. Furthermore, there is no consensus on whether an MPA is effective or not. Thus, how should we measure the effectiveness of MPAs?

Some ways of measuring effectiveness of MPAs have bypassed the importance of the ecological conditions and local communities in the process

The effectiveness of MPAs has been shown in several cases, documenting for example an increase in biomass in the protected area. However, the methodology for measuring the success of the instrument has been the object of discussion in multiple scenarios, especially since the effectiveness depends on the conservation target and on the regulation’s enforcement and management of the MPA.

A measure of effectiveness in many cases seems to be based on broad administrative indicators: whether a management plan is in place, whether the government in charge has legal strategies for the conservation of the MPA, whether economic resources have been made available for its protection, etc.

The 15 indicators most commonly used in the literature to appraise the success of MPAs, reported in 105 articles, testify of this “bureaucratic bias”, since only 4 refer to biophysical indicators, 5 to socio-economic indicators, and 6 to governance indicators. Of the 4 biophysical indicators, only two assessed the status of species in the MPAs in terms of abundance and terms of community composition and structure [49], showing that other important aspects are not being considered in determining conservation success.

For example, although an increase in biomass, in general, can be a positive indicator [50], it cannot be used exclusively to determine the success of an MPA, since they can be mono-specific driven (or monoculture in terrestrial context) or different atmospheric, terrestrial, and oceanic stressors affect the state of ecosystems [51] and that are not totally avoided with

[44] UN General Assembly, 2023
[45] UNEP-WCMC et al., 2023
[46] Secretariat of the Convention on Biological Diversity, 2022
[47] Baruah, 2016
[48] Perry et al., 2020
[49] Gallacher et al., 2016
[50] Smit et al., 2021
[51] Jameson et al., 2002

spatial protection schemes. Suppose the overall objective of MPAs is the conservation of marine ecosystems. In that case, their success should be measured regarding ecosystem conditions using indicators that include anthropic pressures, physical parameters, biological structure, functional structure, and ecological models [52].

Additionally, the effectiveness of MPAs has been measured in the norm under indicators that leave aside the social dimension, which may correspond to a need for more identification of the problems MPAs have in their implementation within the local communities. Although social and ecological dimensions have been recognized as dimensions that influence the effectiveness of MPA conservation, they have yet to be studied [53].

MPAs are not the only tool for the protection of marine ecosystems

MPAs are not the only marine conservation strategy. Different types of Marine Conservation Strategies (MCS) have been implemented, in some cases with greater success than MPAs [54]. Although they may appear similar, and even if in some cases two or more conservation strategies are implemented in the same area, these MCSs display significant differences from MPAs that impact conservation effectiveness. Among MCS are Biosphere Reserves (BR), Marine Fishery Management Areas (MFMA), Indigenous Peoples and Community Conserved Territories and Areas (ICCAs), Ramsar Site (RS), World Heritage Site (WHS). It is thus an open question to assess what are the strategies to be implemented to guarantee the conservation objectives aligned with the current sustainable development agenda, and that would contribute to avoiding the progressive deterioration of marine ecosystems.

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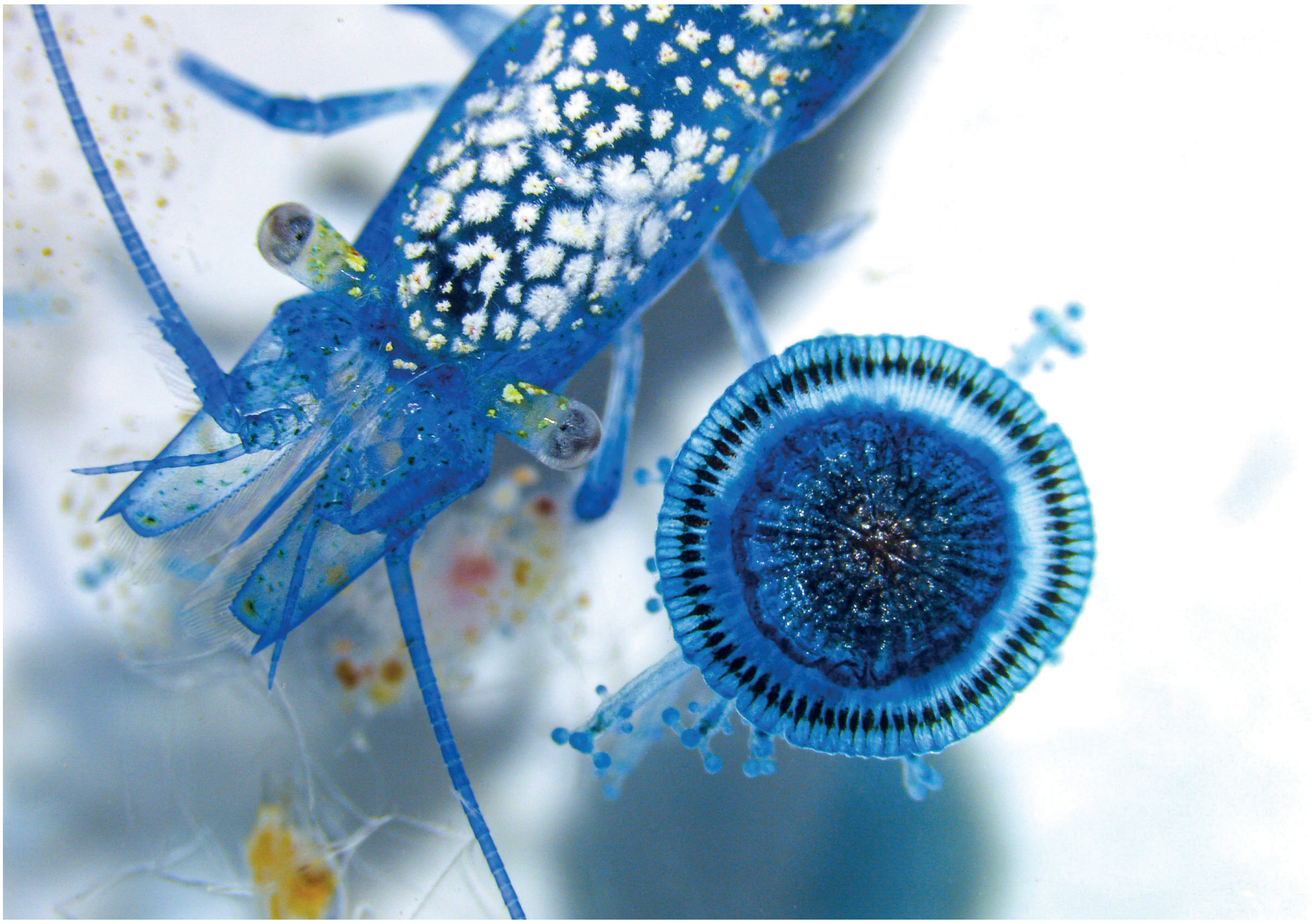
[52] Smit et al., 2021
[53] Meehan et al., 2020
[54] Tran et al., 2020

The importance of understanding and analyzing the ocean at different scales for conservation purposes

Marine ecosystems and their dynamics are complex because ecosystems are composed of multiple (sub)systems connected by the fluidity of water and evolving with its patterns of movement. The understanding of these dynamic processes, spatially and temporally, with repercussions at the functional scale, ought to be applied to conservation strategies [55]. The advance in conservation has generated a wide range of strategies whose primary focus has been to counteract the negative effects of human activities and at the same time to orient conservation to exploitation for the benefit of humans.

In general, all conservation strategies have a common denominator in their design and implementation, as they are all based on the delimitation of conservation zones that follow or establish geographic limits or imaginary borders. Now, although they are precisely represented with maps, they risk betraying natural facts in the marine case, as the sea does not know of these boundaries. The general zoning of marine ecosystems (possibly with poor zoning choices) has caused these tools to be largely inefficient. The problem is not only with the current zoning and its lack of representativeness of marine dynamism. **The effectiveness of these tools has also been affected by a need for more understanding of the *multiple* scales of marine ecosystems and their complexity.**



[55] Kearney et al., 2013

Societal, Ethics and Transparency concerns involving MPAs proposals

Connecting protection to communities

The lack of a societal and cultural vision applied to conservation tools is a concern we must address with robust social studies, addressing long-term outputs and consequences for local communities and territories. Looking at efficiency rates of projects run under limited dialogue with stakeholders and without social concerns shows that in many cases, the history, culture and needs of local communities, including indigenous populations and, in particular, native halieutic species were not adequately taken into account.

In the context of the efforts towards the target of 30% of protected areas, it is essential to state that we need strict rules for biodiversity and restoration of habitats with full protection; at the same time, we cannot ignore some missteps made in the past in the creation of fully protected nature reserves, which resulted in conflicts with and oppression of different native populations [56]. Even recently, we have seen initiatives designing marine parks to develop tourism that failed to respond to local needs, claiming instead that positive economic impacts would have been generated with job creation and tourist activities (e.g., shark and whale watching). Today, many studies show that if the tourism industry in the MPAs can have positive impacts on some local actors, it does not secure a better income for the most fragile populations in the long term, especially if they are led to abandon and lose their traditional practices and livelihoods to enter the tourism industry [57].

Restoring nature and biodiversity is a most urgent objective, and binding measures against industrial fisheries' destructive practices such as deep bottom trawling are needed. But marine reserve proposals cannot be designed without involving local communities (including native fishers) in the definition of the project's objectives and governance, and without respecting cultural differences.

"Blue Bonds" and Market-based financing schemes need to involve participation and transparency

Regarding finance schemes for funding, some projects to introduce MPAs already use market-based tools, through the emission of "blue bonds" or through debt-for-nature swaps. As a part of the collective efforts to bring resources to effectively manage MPAs, much as one should welcome the financial sector's willingness to contribute to fund conservation projects, this intervention must meet ethics and transparency standards. As an example, a recent project in Ecuador to protect the Galapagos with a debt swap funding scheme is a telling case that raises some ethics concerns. As the market-based tools require confidential communications and non-disclosure agreements, the resulting project comes with a low level of local participation, and is *de facto* managed by "northern" organizations, reflecting a vision that is not necessarily aligned with the local Ecuadorian population's priorities.

In a communication released in 2023, the NGO Oxfam, associated with many Ecuadorian networks, states: **"The debt-for-nature swap (...) has been negotiated without providing transparent and timely information to the citizens...It grants to a small and privileged group of foreign private companies the right to decide how to manage a pristine and important conservation area such as Galapagos, undermining the sovereign right and obligation of the Ecuadorian government, both at the central and local level."** [58]

Even if market-based financial tools cannot be excluded from alternatives to ensure concrete funding for conservation tools, their application would require a thorough consideration of ethics, participation and transparency, so as to avoid practices that could be assimilated to a kind of "blue neo-colonialism" or "privatization of the ocean".

[56] Blanc, 2021
[57] Pham, 2020
[58] Latindadd, Eurodad, CDES Ecuador, 2021

The emergence of functional protection: Balancing Genetic Diversity and Ecosystem Roles

Balancing Phylogenetic and Functional Diversity

Marine biodiversity is essential for the health and resilience of ocean ecosystems, which provide critical services such as nutrient cycling, climate regulation, and habitat provision. When measuring marine biodiversity and developing models to maximize it, conservation strategists must balance the focus between two major concepts in biodiversity: Phylogenetic Diversity (PD) and Functional Diversity (FD). PD emphasizes preserving species' evolutionary history and genetic variability, ensuring adaptability to future environmental changes. In contrast, FD highlights species' ecological roles and functions within ecosystems, ensuring immediate benefits like increased productivity and stability.

A knowledge-driven framework for conservation

Integrating PD and FD into a unified conservation strategy can optimize the long-term sustainability of marine biodiversity. PD maintains a genetic reservoir that offers resilience against future threats, making it a forward-looking approach. It is often measured using phylogenetic trees, reflecting the evolutionary distances between species [59]. This approach ensures that genetic diversity is preserved, safeguarding future adaptability. On the other hand, FD focuses on the present health and functionality of ecosystems and uses functional traits. 'Functional Traits' are measurable characteristics of organisms that influence their performance, fitness, and interactions with the environment. These traits affect ecosystem processes, such as nutrient cycling and energy flow. By assessing the range of functional traits within an ecosystem, FD can directly enhance ecosystem productivity, stability, and services like carbon sequestration and water purification [60].

Conservation policies must be informed by detailed ecological knowledge to balance these paradigms effectively. When functional traits and species interactions are well understood, prioritizing FD can optimize immediate ecosystem services. PD should be prioritized to leverage its broad genetic benefits in ecosystems where functional traits are unknown. New methods are needed to determine the sufficiency of ecosystem knowledge to maximize functional diversity (FD). Such a knowledge-based framework can ensure conservation efforts are tailored to the specific needs of marine ecosystems.

Conserving marine biodiversity requires a balanced approach that integrates the immediate benefits of FD with the long-term resilience of PD. A knowledge-driven policy choice in marine conservation offers several advantages. Utilizing real-time ecological data allows conservation strategies to be tailored to the specific needs and characteristics of each marine ecosystem. This dynamic approach ensures that resources are allocated more precisely, making conservation efforts *effective*, allowing policymakers to clearly understand and measure the impact of their actions, and *efficient* in terms of budget allocations. Moreover, a dynamic approach enables policymakers to adapt to changing environmental conditions and emerging scientific insights, enhancing marine biodiversity's overall resilience and sustainability. This strategic flexibility is crucial for addressing the complex and evolving challenges facing marine ecosystems today.

Innovative methods for the economic valuation of coastal and marine ecosystem services

Complexity, dynamic change, and scientific uncertainty characterize marine ecosystem services, i.e. the direct and indirect benefits provided to people by the ocean, including fishing, recreation, flood protection, nutrient cycling, carbon sequestration, and psychological and cultural attachments. Many national and international initiatives have underlined the importance of ecosystem service valuation for conservation and provided detailed approaches and methods [61]. Valuation can contribute to highlighting trade-offs between ocean management strategies by estimating associated benefits and costs and their distribution among different groups. So far, most environmental valuation studies have focused on terrestrial ecosystems. However, the merits of valuation for coastal and marine ecosystems are increasingly recognized, and more valuation is undertaken [62]. Marine ecosystem service valuation must address complexity coupled with significant scientific uncertainty and the unfamiliarity of many people with these services.

[59] Faith, 1992
[60] Cadotte et al., 2011
[61] MEA, 2005; TEEB, 2010; Dasgupta, 2021
[62] Torres and Hanley, 2016

Ecological-economic modeling for addressing the complexity of ESS

One main family of methods for the economic valuation of ecosystem services comprises those based on market data. An important challenge for applying those methods is linking changes in ecosystem functioning to the provision of services already economically valued by humans [63]. This connection is more easily observable for well-identified goods and services like fish harvest and recreation. Less directly observable services like habitat support or pollution control are generally not marketed, so their value is typically estimated by calculating their contribution to marketed goods. This requires an extensive understanding of the ecological dynamics underlying ecosystem services and, thus, an integration of ecological and economic models. A noteworthy example of an integrated ecological-economic approach to valuation is the study by Jänes et al. (2020) [64], who quantified fisheries enhancement from vegetated coastal habitats in Australia. The approach allowed to compare commercial fishing values associated with a seabed without vegetation to a hectare of seagrass, resulting in an estimated average increase of 55,000 fish, commercially worth AUD 21,200 annually.

Deliberation for the construction of values

The other main family of valuation methods includes those based on stated preferences elicited through surveys. They are especially relevant for values completely absent from markets, such as those associated with altruism, caring for the future, and appreciating nature as an end [65]. Given the scarce market valuation of non-material and cultural ecosystem services, stated preference methods are crucial to fill knowledge gaps. However, marine ecosystems are mostly spatially removed from the individuals, communities, and industrial sectors that derive value from them. Thus, the general public has little engagement and experience with offshore marine natural capital, which adds to a perception of remoteness, unfamiliarity, and complexity [66]. Combining stated preference valuation with elements of deliberative democracy, i.e. group discussion and potentially the elicitation of values at the group level, holds the potential to help people learn about and form preferences for complex and unfamiliar ecosystem services such as those provided by coastal and marine ecosystems [67]. Additionally, deliberative settings are more favorable for the emergence of shared and social values associated with self-transcendence and culture [68]. These methods also hold the advantage of generating qualitative data from the group discussions, which can help uncover deeper-held values, motivations, and narratives. They are regarded as a valuable addition to quantitative value indicators.

Deliberative valuation of marine ecosystem services is still rare, but existing research demonstrates its potential. Armstrong et al. (2019) conducted a valuation study on cold-water corals in Norway and Ireland, as an example of remote and unfamiliar ecosystems. They used both an internet survey and a series of deliberative workshops to elicit preferences of population-representative samples. On average, participants were willing to pay between USD 32 and USD 40 per year for increased protection areas of cold-water corals. They were willing to pay the most for protecting areas that are important habitats for fish. Norwegian participants in the deliberative workshops also valued the pure existence of the corals, which was not the case for Irish participants nor for participants who were only surveyed online. Regarding the effect of deliberation, participants stated different preferences on average after group discussion, and the stated preferences became more consistent on the individual level. Additionally, the consequentiality of the study, i.e. participants' perceived likelihood for the results to be used for political decision-making, was significantly higher in deliberative workshops. Those results indicate a high potential for using deliberative valuation methods for marine and coastal ecosystem services to articulate public values for complex and often unfamiliar issues, which are yet of great interest to communities.

[63] Barbier, 2017
[64] Jänes et al., 2020
[65] Cheng et al., 2019
[66] Börger et al., 2020
[67] Armstrong et al., 2019
[68] Kenter et al., 2015

As science progresses, evolving insights and new understandings of value should be integrated into valuation practices

Based on 67 valuation studies, including both market-based and non-market methods, a recent integrated review and meta-analysis of marine ecosystem service values[69] remarks that there needs to be more research interest between different ecosystems. While many estimates exist for coral reefs, other ecosystems like kelp forests, mangroves and seagrass are rarely studied and deep-sea ecosystems such as pelagic systems are almost completely absent from economic analysis. The most prevalent valuation method was value transfer, where values from previously conducted studies are extrapolated to obtain economic measures for different contexts. Thus, value transfer relies on extensive pre-existing research, and value estimates need to be scaled to accommodate both the spatial and temporal characteristics of ecosystems and socio-economic attributes, such as preferences and institutional management. The meta-analysis adjusted for space and time variations using the country's Consumer Price Index and World Bank data on Purchasing Parity Power to homogenize the currencies. The resulting estimates are expressed in USD 2018. Economic values for provisioning services such as fishing and raw material extraction were estimated to range from USD 99 to USD 1535 per hectare per year, for cultural services between USD 45 to USD 2170 per hectare per year, and recreation and tourism services ranged from USD 185 to USD 895 per individual per year. The large differences in estimated values demonstrate spatiotemporal variability in ecosystem services provision, valuation method dependence and scientific uncertainty.

To summarize, there are still large knowledge gaps and great informational value, in valuation research on coastal and marine ecosystem services. Various methods for environmental valuation exist, but they have yet to be systematically applied to ecosystem services provided by the ocean and coastlines. Methods that are especially promising for dealing with those ecosystems' complexity and scientific uncertainty are integrated ecological-economic evaluations and deliberative approaches. **There is an urgent need for increased application of innovative methods to marine ecosystems to more reliably associate economic benefits with ecosystem functioning.**

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[69] Lopez-Rivas and Cardenas, 2024

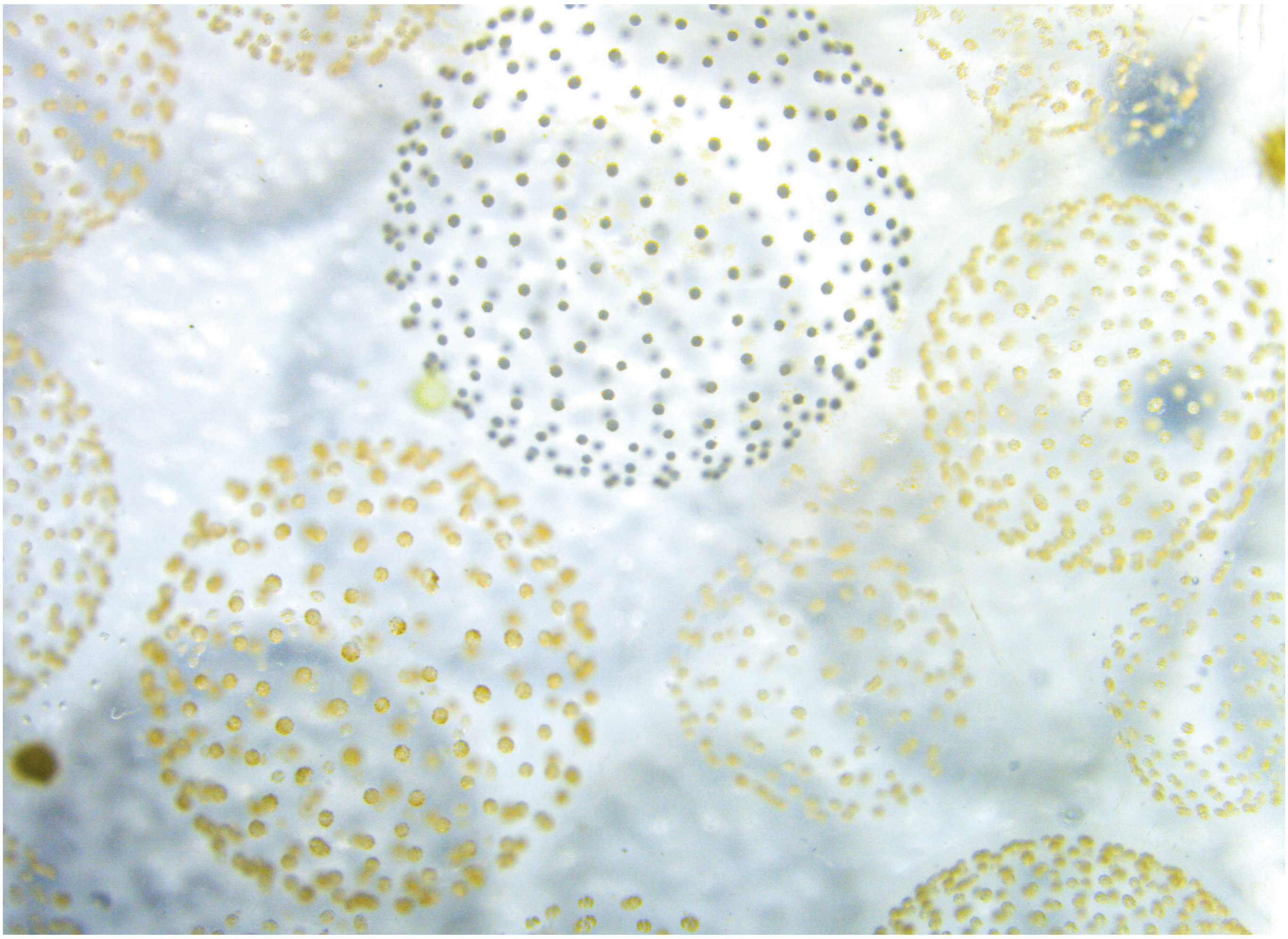
PROPOSALS

Some of the above science-to-policy paths are reflected in existing or in-development proposals. It must be acknowledged that the science-to-policy path requires delicate calibration; at the same time, the moment is ripe to bring into the CBD the role of the new sciences of the ocean.

We discuss two policy proposals/recommendations:

1. Dynamic, Data-Driven Marine Conservation Strategies: Leveraging advanced data analysis and machine learning to identify and protect critical plankton ecosystems and dynamic marine areas, aligning conservation efforts with the ocean's temporal and spatial variability.

2. Legal and Ethical Frameworks for Marine Ecosystem Protection: Marine ecosystems should be granted legal rights to their integrity. Data-driven models should be used to define and measure ecosystem integrity, and sustainable Intellectual Property Rights models should be developed that compensate ecosystems for resource use.



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Key Ocean Planktonic Areas (KOPAs)

The scientific expeditions led by the Tara Ocean Foundation for more than ten years have helped to put together a meaningful, comprehensive, and open-access database of measurements on one of the first bricks underlying all the services provided by the oceans: plankton. The holistic approach proposed by the *Tara Oceans* scientific program has the potential to generate knowledge of the entire marine ecosystem while bringing forward the **tools to create innovative and evidence-based biodiversity protection regulation.**

The recent developments of marine scientific programs using genomics, high-definition microscopy, and bioinformatics tools have made it possible to produce and analyze a vast amount of quantitative data. The ongoing scientific exploration of the plankton will allow us to identify better correlations, functions, and symbiosis between organisms and estimate values for essential ecosystem services provided by the plankton. Defining tools to quantify these three services as markers for climate services and food security would provide scientists and decision-makers with a common ground to identify, monitor, predict changes, and protect crucial plankton ecosystems. The implementation of such tools would have a truly global cascading effect: from sustaining plankton and marine biodiversity in general, down to providing better predictions for fish stocks and ensuring the continuity of human activities related to the oceans, via supporting the storage of carbon in the global oceans and mitigating climate change.

With the urgent need to address solutions in the frame of current international and regional processes such as the UN Global Biodiversity Framework or the EU Nature Restoration Law, it is essential to link ocean protection to ecosystem functions and climate services. Yet current methodologies and metrics used to create Marine Protected Areas (MPAs) or Area-based management tools (ABMTs) are mostly based on a phylogenetic and taxonomic approach, failing to address climate and functions with robust and quantitative data.

In this context, the Tara Ocean Foundation, within the Plankt'Eco project[70], is proposing **new tools to define hotspots of plankton services as Key Ocean Planktonic Areas (KOPAs) based on the existing KBAs** (Key Biodiversity Areas, today used mostly on terrestrial and coastal biodiversity). The aim is to build methodology and metrics to inform decision-makers on how to **identify areas where climate services are being "provided" by ocean life, and where it is more intense and essential to marine life itself, but also for human societies and the planet as a whole.**

Such a legally binding recognition scheme could be an essential first step towards defining appropriate mechanisms to protect areas with seasonal phenomena, such as plankton blooms, at the moment they happen, and mobile areas of biodiversity that move according to ocean conditions. Given the ubiquitous presence of plankton and their proven importance in mitigating climate change, pollution, and biodiversity loss, we firmly advocate that it is important to better study and understand these microscopic ecosystems to design conservation strategies to protect ocean life.

[70] The Plankt'Eco project is funded by the French Facility for Global Environment (FFEM) and the French Biodiversity Agency (OFB)

Leveraging data mining for assessing KOPAs ecosystems services

Historically, ocean studies and oceanography have been reductionist. They aim to describe the ocean system via different factors, reduce a multidimensional data space (i.e., one dimension per measured factor), and extract significant variables to be mapped (i.e., emblematic species, molecules, or pH). These variables are further considered in investigating ocean status but do not allow for simulta-neously assessing the ocean system on different scales (from organismal physiology to ecosystems). In particular, **microbiomes are increasingly credited with driving ecosystem functioning, biogeo-chemical cycling, and dysbiosis or health of ocean systems**. However, a grand challenge in the life sciences is establishing agile and mechanistic modeling approaches to 'translate' gene and taxon lists that arise from myriad sequence-based 'meta-omic' survey techniques into predictions of ecosystem outputs, aka ecosystem services. This challenge is exacerbated when considering the many scales of biological complexity that span from the molecular and cellular through interacting organisms that comprise ecosystems that scale further to regional and even planetary-scale features.

Key Ocean Planktonic Areas must follow these recent advances in ocean system studies to ensure more efficient and comprehensive protection. Notably, a critical development in this area is the rise of new data sources for studying the ocean. Ocean sciences are indeed taking an unprecedented shift in the form of an exponential increase of data from ocean's physics, chemistry, ecology, and biology [71]. Processing and analyzing these data allow for a better understanding of the Ocean as a system and opens up new areas of study beyond traditional oceanography. A key element in this shift is the recent use of computational sciences that abstract and predict ocean systems' dynamic changes.

Among computer sciences, advancements in Machine Learning (ML) technologies offer promising tools for addressing critical environmental challenges. ML can enhance our ability to detect and analyze genes associated with essential climate-related features, such as carbon export [72], net primary production (NPP), and biodiversity metrics like the Shannon index. This technology can revolutionize the design of novel genomic markers that improve our understanding of ecosystem responses to climate change. By leveraging ML-driven genomic insights, policymakers and researchers can better forecast ecological shifts and develop more targeted strategies for biodiversity conservation and carbon management, thereby contributing to climate resilience.

Besides the use of omics for climate prediction sake, the genetic makeup of marine organisms is crucial for defining different oceanic regions and categorizing ecosystems based on their biological composition [73]. Using Artificial Intelligence (AI) modeling, we can move beyond merely describing these regions and create comprehensive models of the metabolic processes at the genome level. These AI-driven models help us understand the biochemical capabilities of these ecosystems by encapsulating their metabolic functions and interactions. This allows for a more accurate evaluation of ecosystem services like nutrient cycling and carbon sequestration. By incorporating these insights into environmental policy, we can improve the management and conservation of oceanic ecosystems, ensuring their sustainability and the continuation of the essential services they provide.

[71] Sunagawa et al., 2020
[72] Guidi et al., 2016
[73] Richter et al., 2022

Modeling the right of marine ecosystem to their own integrity

A recent trend in ecosystem governance consists of granting ecosystems legal standing and subjective rights. This legal move goes beyond the recognition that an ecosystem approach is required in "standard" marine environmental law. The idea is that the obligation to maintain the integrity of ecosystems can find its normative source in subjective rights of those ecosystems themselves. However, even if the rights of ecosystems to their own integrity have at times been granted at a local or national level, they have been regularly rejected in court by being judged impracticable and failing a criterion of proper definition, which undermines their legal effectiveness and makes them fall under the objection of "unconstitutional vagueness".

We propose **to take advantage of the massive increase in data acquisition and the more predictive understanding of the dynamics of oceanic ecosystems to dissipate these legal uncertainties**. The availability of data on marine microbial ecosystems, particularly those captured by metagenomics and autonomous sensors, creates an opportunity for applying broader modeling techniques that embed data-driven approaches. The overarching idea of our use of oceanological numerical modeling to assess the inherent structure of a given ecosystem. A given ecosystem could exhibit distinct modes or statuses following its stimulation or perturbation. Accumulation of data and its systematic exploration will assess the definition of these modes and their intertwined via mathematical structures. In that approach, some modes are extreme, and one assumes that inner modes within these extreme states are combinations of the extreme ones. Therefore, extreme modes define the system's limits and integrity that one aims to protect. If a perturbation promotes a new state, we can numerically quantify the change in the mode definition (i.e., assess the mode hypervolume change after the perturbation) and thereby approximate the damage borne to ecosystem integrity. Conversely, if a perturbation promotes a new state inside the existing mode, the integrity of the ecosystem is not harmed.

The notion of the integrity of an ecosystem is a common denominator of major international environmental regulatory platforms and instruments. It surfaced in the Convention on the Conservation of the Antarctic Marine Living Resources (CCAMLR) in 1980, which stated "the importance of safeguarding the environment and protecting the integrity of the ecosystems of the seas surrounding Antarctica." Article 1.1(4) of the 1982 UNCLOS sets the objective to protect the integrity of the marine environment. The notion of ecosystem integrity pervades most active frameworks of international environmental law. For instance, Part IV of the 1997 UN Watercourses Convention includes several articles on protecting the integrity of ecosystems (from pollution or invasive species) and explicitly defines itself as an "ecosystem approach" to be generalized in international law. Different States have endorsed that approach, although it has also been criticized for its elusiveness and the governance fragmentation it induces. International environmental litigation has also recently mobilized the notion of "pure ecological damage" done to ecosystems (e.g., "Costa Rica v. Nicaragua", February 2, 2018), with the International Court of Justice requiring for the first time reparation for environmental damage for the sake of the environment itself.

However, the evaluation of the "pure" damage inflicted to the environment, by contrast to the assessment of different types of value loss imposed on human interests, still lacked a rigorous definition, leaving the judge with insufficient information as to the measure of the damage and its associated judicial consequences. With a data-driven model-based notion of the ecological integrity of a marine ecosystem, we propose the possibility of opposing to any defendant the measurable perturbation of that ecosystem's integrity. This approach can systematically be associated with degrees of rights violations and thereby help determine graded penalties, providing a judge with less reason to invoke an "unconstitutional vagueness" for the use of the concept of ecosystem integrity.

Imagining sustainable intellectual property protections in the high seas

The last round of BBNJ negotiations which ensued in the final draft still to be ratified by more than 60 States to be effective, has relinquished any discussion about Intellectual Property Rights regulations about the tricky issue of use and patentability of marine genetic (and more generally biological) resources originated in Areas Beyond National Jurisdiction. This means that using those resources in technological innovation (in industries such as pharmaceutics, chemistry, and cosmetics) has yet to give rise to any new conception of how the common heritage of humankind, which the high seas represent, could be compensated for the resources it provides. This also means that the principle of the freedom of the seas rather than this very principle of a common heritage still dominates concerning the conception (or absence thereof) of Intellectual Property (IP), at least for the moment.

We propose an alternative IP rights model that would acknowledge and reciprocate the utilization of ABNJ marine resources for innovation. This innovative construct, rooted in principles of Nature rights, disrupts conventional legal and economic perspectives. **It views both marine resources as an object of utility and the ecosystems they stem from as a legitimate rights-bearing entity, echoing the philosophical tradition of rights theory.**

In this newly suggested nature-rights IP model, a managing legal entity would be established to represent and manage the nature rights of a specific marine ecosystem located within the common heritage of humankind, in a way this has been done for other segments of nature, such as a river, a mountain, or a species. Integrating Geographical Indications (GIs), the Convention of Biological Diversity's (CBD) Nagoya Protocol, and patent law, this model proposes a comprehensive IP paradigm that aligns with law and economics scholarship. GIs secure the economic and ecological uniqueness inherent in geographically specific natural resources, reflecting an understanding of place as a legal and economic construct. The Nagoya Protocol, on the other hand, draws on principles of distributive justice to facilitate fair benefit-sharing from genetic resource utilization. Its adaptability to a BBNJ framework has been under investigation during the negotiation phases. Yet the need to extend IP negotiation to a multilateral framework (instead of bilateral agreements) still needs to find its way to the final document. The nature-rights IP approach we propose takes stock of these difficulties and we substitute the idea of a legal entity managing IP compensations for ecosystems based on ABNJs.

Under this nature-rights IP model, using ABNJ natural resources for innovation would require obtaining a license from the managing legal entity representing the rights of the ecosystem. The license would include a compensation mechanism ensuring *nature is compensated for using its resources*. The compensation could be financial or in-kind contributions, such as investments in conservation efforts, restoration projects, or other sustainable development initiatives. The model thus integrates legal and economic theory, endorsing sustainable use of natural resources while acknowledging nature's inherent rights. It could help fill a gap within the current state of the BBNJ treaty or, at least, orient some discussions at the junction of BBNJ, WIPO, and WTO, since the philosophy of the BBNJ negotiators had been to prevent internalizing within the treaty the discussions of topics, such as precisely IP, that would be the object of externation discussions between relevant international organizations.

SUMMARY OF POLICY RECOMMENDATIONS

The main thrust of the present Policy Brief is that current Marine Conservation Strategies, mainly static and defined through the establishment of geographic boundaries, should consider temporal and functional scales of ecosystems and not only spatial scales, in this sense the understanding of these scales will allow a more adequate representation of marine ecosystems and therefore implement strategies more appropriate to oceanic dynamism. This general direction is articulated in a series of recommendations.

1 Complementing marine conservation strategies

Current Marine Protected Areas, on many occasions, have been reported as difficult to implement and inefficient strategies; however, when properly implemented, they have positive effects on ecosystems, although reality shows that they are not adequate tools for the global drivers of biodiversity and ecosystem loss such as climate change. Therefore, these strategies must be complemented with more effective strategies to mitigate global drivers, so it is important to advance in the understanding of these, but not to rely solely on them for the conservation of marine ecosystems and their species.

2 Using knowledge to drive conservation strategies

Marine biodiversity conservation policies should incorporate both Functional diversity (FD) and phylogenetic diversity (PD) to enhance ecosystem functioning and resilience. In the norm, one should prioritize FD in ecosystems where functional traits and species interaction are well-documented to optimize immediate ecosystem services, while emphasizing PD in less-studied ecosystems to preserve long-term evolutionary potential. Conservation strategies must be informed by ecological data to allow for adaptive management that maximizes biodiversity outcomes.

3 Incorporating the temporal/dynamic dimension

Incorporating the temporal/dynamic dimension in Marine Protection Policies, in particular order to make the acceptance of moratoria widespread, and to introduce flexibility in the trajectories of MPAs.

4 Developing and fine-tuning of Valuation of marine ecosystem services with innovative methods

Valuation efforts of marine ecosystem services, as compared to terrestrial ones, are still scarce, and assessments of economic values often resort to benefit transfers. We propose to undertake original valuation under careful consideration of the specific ecological and social characteristics of the issues at stake. We highlight that valuation does not constitute a solution to environmental problems, but should be accompanied by policy measures and respond to their valuation needs. Integrated ecological-economic modeling and deliberative valuation have been shown to be useful for dealing with ecologically and socially complex issues.

5 Developing Intellectual Property Rights for marine ecosystems

Given the complexities of implementing fair and efficient Intellectual Property Rights regimes in the context of BBNJ (Biodiversity Beyond National Jurisdiction) and the challenges in extending the provisions of the Nagoya Protocol in this area, a proposal is made to fund an international marine conservation body through a system of royalty percentages. These royalties would be refunded from the profits gained through the innovative use and patenting of marine resources (biological, genetic, and mineral) traceable to their exploitation.

6 Fostering legal representation of marine ecosystems' integrity

Numerical oceanology data-driven modeling of the space of parameters within which a marine ecosystem remains viable, allows for a measure of violations of ecosystem integrity and links them to legal infractions. The legal concept of ecological integrity, along with the ecosystem's right to maintain it, first emerged in 1980 in the Convention for the Conservation of Antarctic Marine Living Resources, emphasizing the protection of Antarctic marine ecosystems. Scientific advances have lent rigor and applicability to this legal approach.

The above proposals have been designed bearing firmly in mind **societal and ethical concerns**. Much as establishing fully Protected areas is a priority in the frame of the GBF's 30X30, MPAs (and, in general MCS) proposals cannot be introduced without a social and cultural vision, and including local communities in the definition of the project's objectives and governance. In particular, as to Finance tools and MPAS funding, the creation of financial products such as Blue Bonds and other derivatives based on ocean assets and values should be followed by transparency and ethics rules to prevent financialization and risks associated with market fluctuations.

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