

# The Blue Acceleration: The Trajectory of Human Expansion into the Ocean

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Does humanity's future lie in the ocean? As demand for resources continues to grow and land-based sources decline, expectations for the ocean as an engine of human development are increasing. Claiming marine resources and space is not new to humanity, but the extent, intensity, and diversity of today's aspirations are unprecedented. We describe this as the blue acceleration—a race among diverse and often competing interests for ocean food, material, and space. Exploring what this new reality means for the global ocean and how to steer it in a sustainable and equitable way represents an urgent challenge.

## Introduction

The ocean has been a source of food and a venue for transport and trade essential to the development of civilization.<sup>1</sup> Although human activity at sea was once primarily limited to shallow coastal areas, technological advances over the past decades have rendered even the most remote parts of the ocean accessible.<sup>2</sup> Commercial interest in the ocean has also increased as land-based sources become fully exploited or exhausted, because of continued population growth and increasing per capita consumption in many parts of the world.<sup>3</sup> As a result, costly endeavors such as commercial mining of the deep seabed are now considered not only feasible but imminent.<sup>4</sup> Likewise, the search for novel bioactive compounds to address antimicrobial resistance is increasingly focused on remote deep-sea microorganisms,<sup>5</sup> whereas space constraints on land have contributed to the construction of large-scale offshore wind farms and investment in deep-water installations.<sup>6</sup>

The subsequent recognition of the ocean as a new economic frontier, which covers more than two-thirds of the Earth's surface, has led to considerable investments that are driving growth in existing industries and the emergence of new ones, spanning an increasingly diverse range of activities.<sup>7</sup> In parallel, scientists and civil society organizations have called for exploration before exploitation<sup>8</sup> and looked to the ocean as key for achieving climate and broad societal goals.<sup>9</sup> Consequently, the hopes and expectations for the ocean to sustain future human needs are increasing and have become ubiquitous (Table S1).

As the capacity to industrialize the ocean grows, marine ecosystems face unprecedented cumulative pressures from human activities and climate change.<sup>10–12</sup> Ocean acidification, marine heatwaves, plastic pollution, and ecological connectivity all transcend political boundaries, making the sustainable governance of marine resources a uniquely international responsibility.<sup>13–16</sup> The rhetoric of a “blue economy” that would combine economic growth with sustainable use is increasingly finding its way into national and international policy documents.<sup>17</sup> Yet this is unfolding in a complex and uncertain governance landscape,<sup>18,19</sup> and concerns have been raised over competing interpretations of what the blue economy entails, and who it is supposed to benefit.<sup>20,21</sup>

Here, we synthesize and assess the trajectories of multiple ocean claims with relevance for ecosystem sustainability, human well-being, and economic growth. We review their impacts and use case descriptions to illustrate the diversity of ocean claims, their complex interactions, and the associated risks. Finally, we propose how academics, policy makers, and practitioners can help to reconcile the diversity of ocean aspirations, accommodate these within biosphere limits, and ensure they are aligned with international commitments to promoting equity.

## Ocean for Food, Material, and Space

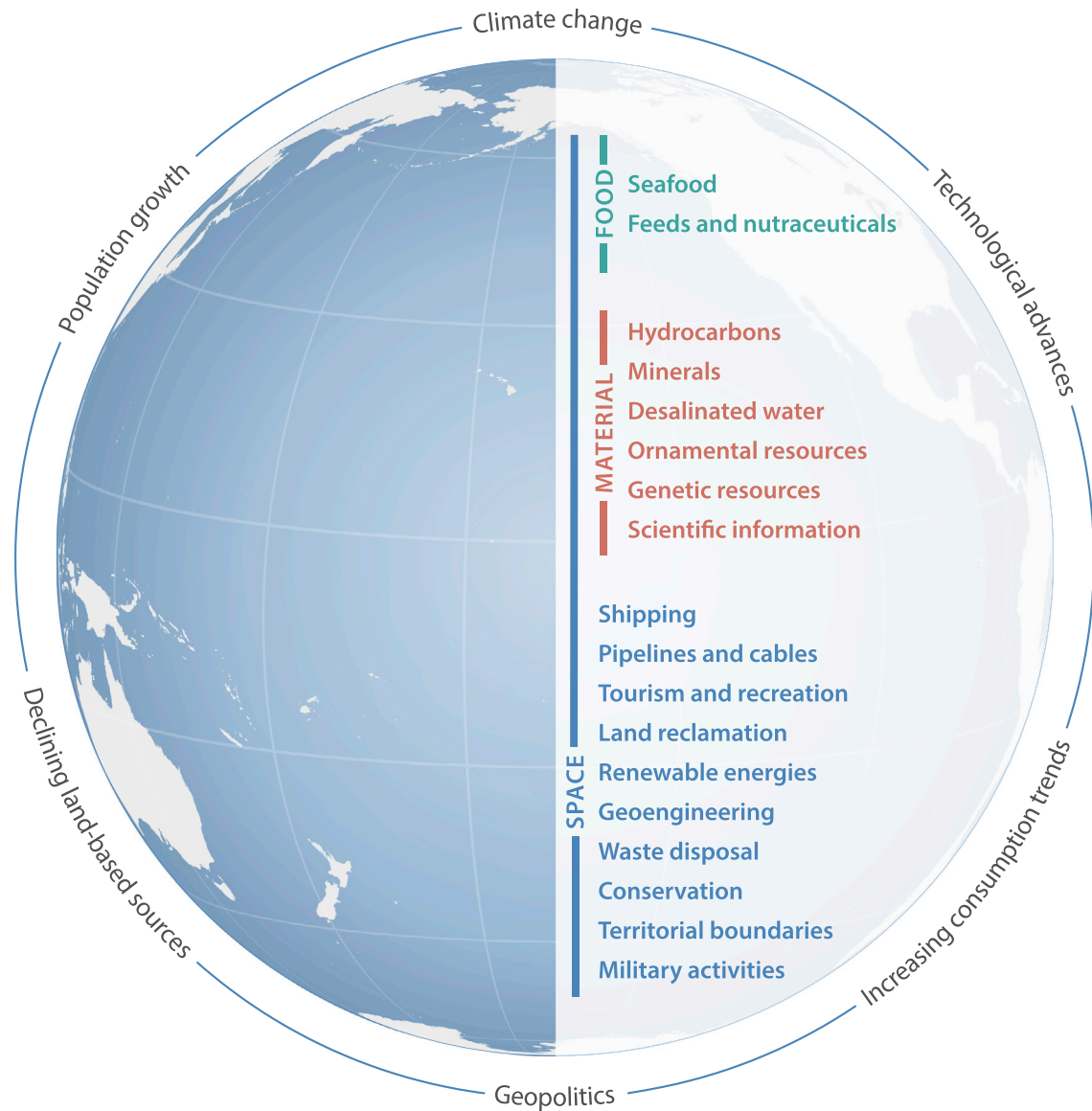
The capacity to maintain a healthy ocean for the well-being and prosperity of current and future generations hinges on understanding the new global ocean context and unpacking the diversity of existing claims (Figure 1). Traditionally, scientists and policy makers have looked at impacts or individual industries,<sup>7,12,22</sup> but a focus on claims makes it possible to account for a wider array of uses, expectations, and societal values attached to the marine environment. It also helps to anticipate human action before the impacts unfold. A comprehensive review of ocean claims is found in Note S1; we summarize them below under three fundamental needs for humanity: food, material, and space (Figure 1).

## Ocean for Food

The seas have been an important source of food for coastal communities through the provision of fish, shellfish, mammals, marine reptiles, seabirds, and seaweed for millennia.<sup>23</sup> Over the past half-century, however, increasing demand and technological progress have enabled rapid industrialization of the fishing and aquaculture sectors.<sup>12,24</sup>

Since the 1960s, seafood has been the world's fastest-growing food industry, and fish has become one of the most-traded food commodities.<sup>25</sup> The seafood sector is the largest employer among ocean-based industries, providing millions of jobs and a vital source of proteins and micronutrients to billions of people.<sup>7,25</sup> Not only is fish increasingly regarded as a critical component of global food and nutrition security,<sup>24</sup> it is also one of the only sources of animal protein, depending





**Figure 1. Ocean Claims**

The ocean is increasingly regarded as an engine of present and future human needs for food, material, and space. Claims were identified and categorized through an iterative process aimed at understanding ocean uses of direct relevance for ecosystem sustainability, human well-being, and economic growth. Around the globe are some of the key distal drivers shaping this new global ocean context. See [Note S1](#) for methodology and details on each claim.

on the species and how it is produced, for which further growth in global consumption is deemed possible within environmental limits.<sup>26</sup>

Wild-capture volumes peaked around the late 1990s and have remained stagnant since then (Figure S1), despite fish being caught at greater depths<sup>27</sup> and farther distances.<sup>28</sup> Future potential for increasing wild harvest lies in improved management of stocks<sup>29</sup> and the exploitation of untapped resources such as fish occupying lower trophic levels or mesopelagic populations.<sup>30,31</sup> In contrast, both the number of aquatic organisms domesticated for farming and their production volumes have dramatically increased over the past decades<sup>32</sup> (Figure S1). Marine aquaculture is expected to further expand in coastal and offshore areas, as limitations on aqua-feed supply are addressed,

and with the development of regional socio-economic and technological capacity.<sup>33–35</sup>

The ocean also contributes indirectly to human nutrition when fisheries products, such as fishmeal and fish oil, are used as key ingredients in animal feeds for aquaculture and livestock.<sup>36</sup> A recent analysis estimated that 27% of marine fisheries landings from 1950 to 2010 were destined for uses other than direct human consumption.<sup>37</sup> Investments in alternative feed sources have also led to the development of new transgenic oilseed crops based on sequences from microalgae,<sup>38</sup> while the range of ocean products used as nutraceuticals has seen a rapid expansion.<sup>39</sup> Combining the terms nutrition and pharmaceuticals, nutraceuticals are foods containing bioactive molecules with health benefits that extend beyond nutritional value. Marine

nutraceuticals, such as omega-3 fatty acids from krill, represent an increasingly large portion of the global nutraceutical market, expected to reach USD 385 billion by 2020.<sup>40,41</sup>

### **Ocean for Material**

Materials derived from the ocean encompass a range of abiotic, biotic, and intangible resources (Figure 1, Note S1). The combination of increasing global demand, technological progress, and declining land-based sources have made extraction of a growing number of ocean materials not only feasible but economically viable. The associated industries are characterized by high levels of anticipation for future growth as well as high entry costs.<sup>42</sup>

Accounting for one-third of the total value of the ocean economy, the oil and gas sector is the largest ocean-based industry.<sup>7</sup> Nearly 70% of the major discoveries of hydrocarbon deposits between 2000 and 2010 happened offshore, and as shallow-water fields become depleted, production is moving toward greater depths (Figure S2). In addition, the seafloor holds the promise of vast quantities of natural gas hydrates, which are evenly distributed across the planet and are estimated to represent twice as much organic carbon as the world's coal, oil, and other forms of natural gas combined.<sup>43</sup>

Aggregates such as sand and gravel have become the most mined minerals in the marine environment because of increasing global demand from the construction industry.<sup>44</sup> Likewise, the surge of interest in minerals from the deep sea is linked to a growing demand for metals to sustain the development of high-tech products, including those needed for a low carbon future.<sup>45,46</sup> Exploratory mining licenses have been granted for more than 1.3 million km<sup>2</sup> of the seabed in areas beyond national jurisdiction, and exploitation regulations are expected to be approved within the next 2 years.<sup>46</sup> Desalination of seawater has also gained attention in the context of escalating freshwater scarcity due to climate change and coastal urbanization.<sup>47</sup> Desalination facilities worldwide include about 16,000 operational plants with a global capacity of more than 95 million m<sup>3</sup> per day.<sup>48</sup> Desalination of seawater accounts for the largest volume (59%), followed by brackish water (21%) and other less saline feedwater. New ocean-water desalination projects are on the rise, including floating desalination plants constructed on ships and offshore structures, which have the advantage of being mobile.

Interest in the ocean goes beyond resources that are declining on land to also include the exploration of new frontiers and extraction of material unique to the ocean, such as ornamental species and marine genetic resources.<sup>49,50</sup> Ocean biodiversity is of particular interest for bioprospecting because many organisms have evolved to thrive under extreme conditions of pressure, temperature, salinity, or darkness, making their genetic code the subject of commercial interest for a wide range of industries (e.g., pharmaceuticals, nutraceuticals, chemicals).<sup>38,51</sup> Enabled by advances in sampling technologies and remotely operated vehicles, over 34,000 natural products have been described from species found in the ocean (<http://pubs.rsc.org/marinlit/>). Commercial uses of genetic resources are closely linked to, and in many cases reliant upon, the non-commercial research that has produced vast databases of genetic sequence data<sup>52</sup> and continues to generate knowledge from the ocean.<sup>53</sup>

### **Ocean for Space**

Claims on ocean food and material—facilitated by infrastructure such as fishing boats, aquaculture farms, offshore platforms, and deep-sea mining equipment—all require space in the ocean. However, the ocean space also provides the basis for a multitude of activities at sea that do not involve the extraction of food or material (Figure 1, Note S1).

From the spread of ideas to early trade routes, the ocean has been and still is central to globalization. The introduction of container shipping in the late 1960s revolutionized maritime transport, which now accounts for over 80% of global trade by volume and more than 70% of its value.<sup>54</sup> Likewise, 1.3 million km of undersea fiber optic cables carry 99% of international telecommunications, offering more reliability, speed, capacity, and cost advantages than satellite communications.<sup>55</sup> Submarine pipelines, too, have rapidly expanded to keep up with the development of the global offshore oil and gas industry.<sup>56</sup>

Ocean space is also inherently needed for marine and coastal tourism, the second largest employer in the ocean economy and one of the fastest-growing segments of the world's tourism industry.<sup>7,57</sup> More than 40% of the global population lives in areas within 200 km of the ocean, and 12 of 15 megacities are coastal.<sup>58</sup> As the population, economic activity, and urbanization keep increasing in coastal areas, land reclamation has become critical to resolve land shortages and accommodate the increasing need for urban and industrial spaces.<sup>59,60</sup> China, in particular, is leading the world in large-scale reclamation projects, extending its coastline by hundreds of square kilometers every year.<sup>61</sup>

Marine renewable energies derived from wind or waves are among the solutions with the greatest potential for meeting the increasing global energy demand while reducing carbon emissions.<sup>62–64</sup> The majority of turbines and large-scale wind farms have been installed close to shore but recent studies indicate the possibility of even greater wind power generation over open ocean areas, spurring the development of technologies to harvest wind energy in deep water environments.<sup>6</sup> In addition, and despite being much debated, marine geoengineering is increasingly suggested as a way to sequester carbon, either in the sub-seabed or via ocean fertilization.<sup>65,66</sup> This is a special case of ocean dumping, otherwise supposedly restricted to dredged material, fish waste, and human-made structures.

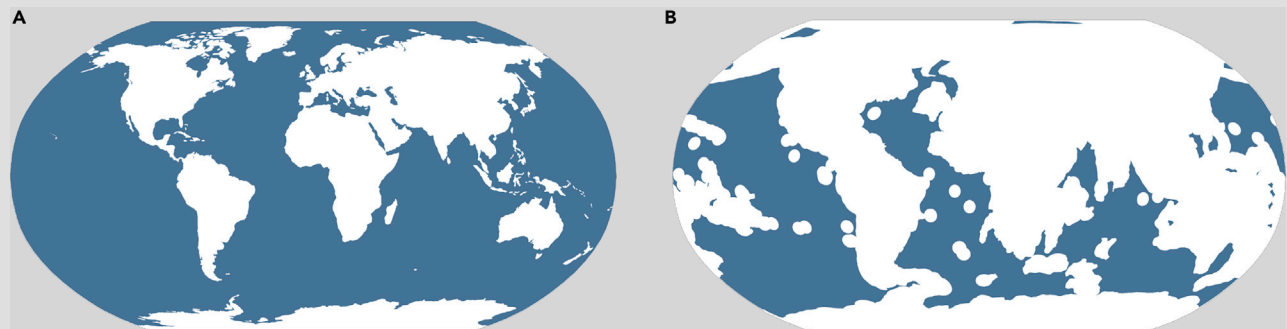
Spatial claims on the ocean also aim at limiting resource exploitation, most prominently through the designation of marine protected areas.<sup>67</sup> Coastal states have committed to safeguard at least 10% of the marine environment by 2020, while scientists and non-governmental organizations have begun calling for a more ambitious coverage of at least 30%.<sup>68,69</sup> Likewise, the notion of sense of place and the recognition of the esthetic, cultural, spiritual, indigenous, and otherwise non-monetary values associated with the sea are becoming increasingly visible in academic debates and policy processes.<sup>70,71</sup> Finally, the ocean space is highly geopolitical, because it is codified into different maritime jurisdictions (Figure S3) and offers an arena for nations to assert their influence and engage in military activities.<sup>72</sup> The prospect of commercial exploitation of the seabed, for instance, has recently led many countries to claim extended rights of national sovereignty over ocean space, with each granted claim diminishing the area designated as the common heritage of humankind (Box 1).

**Box 1. Seabed Grabbing**

One of the most significant geopolitical transformations in recent times is occurring in the ocean depths.<sup>73</sup> Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS) allows countries to claim an extended continental shelf to explore and exploit the resources of the seafloor beyond the 200 nautical miles of their exclusive economic zone.<sup>74,75</sup>

Since the first claim was made by Russia in 2001 concerning the Arctic region, submissions or preliminary information from a total of 83 countries have been sent to the UN Commission on the Limits of the Continental Shelf, together encompassing more than 37 million km<sup>2</sup> of the seafloor (Note S1). This is more than twice the size of Russia—the world's largest country—and nearly 80 times the reported global area of “land grabs” since 2000 ([www.landmatrix.org](http://www.landmatrix.org)). In many cases, the territorial basis of a state is made of more seabed than land. Small island developing states are indeed becoming large ocean states. The Cook Islands, for instance, has claimed an area of extended continental shelf equivalent to 1,700 times its land surface. Countries that include islands and overseas territories are benefitting in particular from Article 76. Remarkably, Australia was able to secure more than 2.5 million km<sup>2</sup> of additional seabed thanks to Heard Island and the McDonald Islands, two uninhabited territories of 368 and 2.5 km<sup>2</sup>, respectively.<sup>76</sup>

This recent surge in submissions has also given rise to several overlapping claims, adding an extra dimension to maritime disputes and foreshadowing the need for future negotiations on boundary delimitation agreements.<sup>77,78</sup> Overall, the expansion of national sovereignty rights over maritime space raises issues of equity and benefit sharing since only a limited number of states have access to an extended continental shelf, and every claim happens at the expense of the area of the seabed and subsoil located outside national jurisdiction. The extension of the continental shelf is therefore not only transforming the geopolitical landscape, it is also substantially shrinking the area designated as the common heritage of humankind.



The figure shows (A) landmass under national jurisdiction versus (B) landmass and seabed under national jurisdiction. The expansion of rights of national sovereignty over maritime space, including exclusive economic zones and claimed extended continental shelves, happens at the expense of the global ocean commons. Based on the extended continental shelf claims submitted as of 2019, only 48% of the seabed would remain as humanity's shared inheritance. Note the exception of Antarctica, currently governed under the international Antarctic Treaty System and for which claims are made in anticipation of 2048 when the treaty will become modifiable. See Note S1 for details and data sources.

Claiming the ocean for food, material, and space is not new to humanity, but the current rush for the ocean is unfolding with unprecedented diversity and intensity. We describe this as the blue acceleration (Figure 2), a new phase in humanity's relationship with the biosphere, where the ocean is not only crucial for sustaining global development trajectories but is being fundamentally changed in the process.

**The Blue Acceleration**

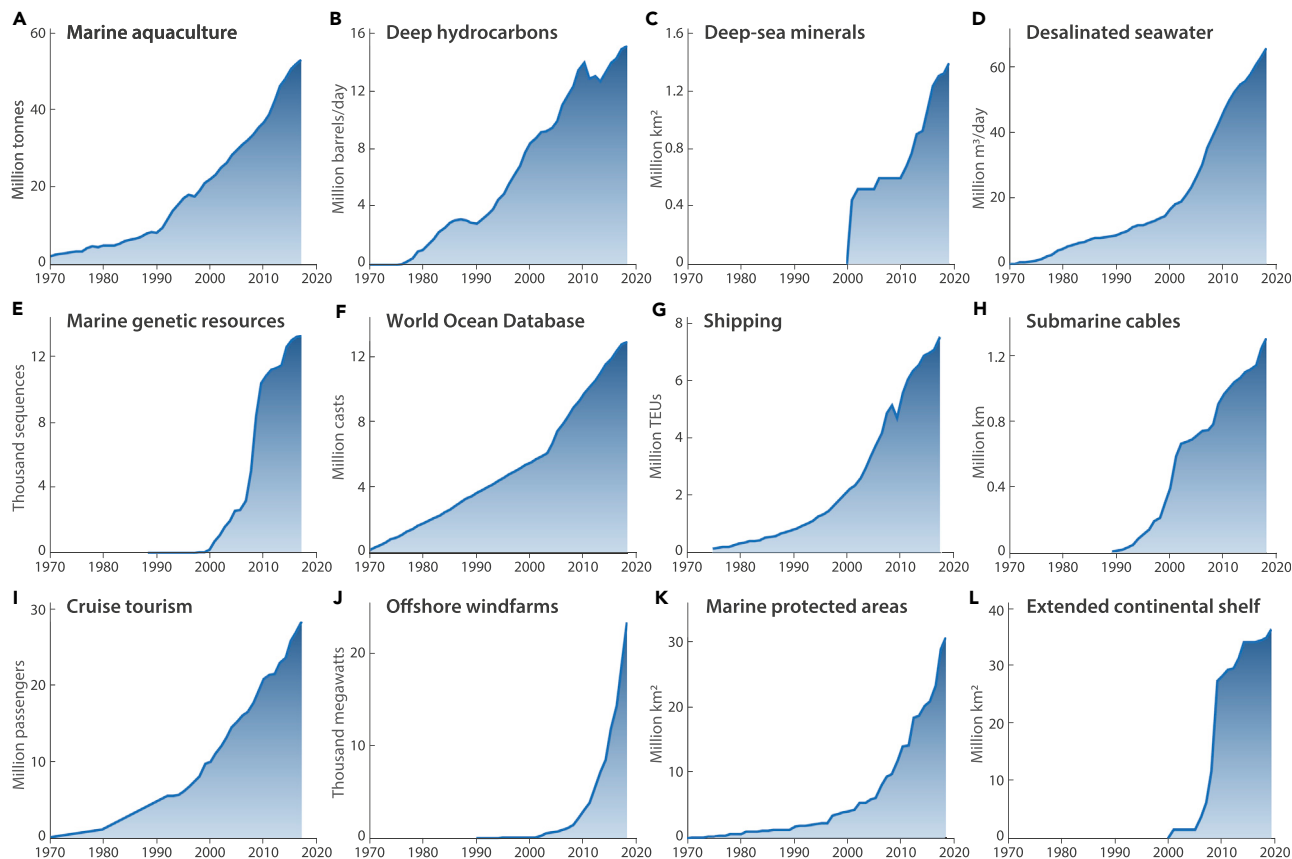
The multitude of claims that collectively illustrate the blue acceleration exhibit a phenomenal rate of change over the last 50 years, with a sharp acceleration characterizing the onset of the 21<sup>st</sup> century (Figure 2). With claims extending across renewable and non-renewable resources, and entailing both mobile and stationary activities, the blue acceleration is intensifying the pressure on the ocean (Table S2) and leading to a range of synergistic, antagonistic, and additive interactions between claims.<sup>2,79–81</sup> For example, offshore hydrocarbon operations have an impact on wild-capture fisheries through the displace-

ment of fish stocks and altered fish biochemistry,<sup>82</sup> submarine pipelines and cables prevent trawl fishing, and large offshore wind farms may conflict with coastal tourism and recreational activities. In other situations, claims can benefit from each other, such as marine research enabling bioprospecting,<sup>83</sup> or the establishment of marine protected areas increasing fish biomass and potential catch gains in neighboring areas.<sup>84</sup>

As the blue acceleration unfolds, the impacts of claims will increase (Table S2) and new dynamics will emerge. Below, we use case descriptions to illustrate different aspects of how the blue acceleration manifests and what this implies for the emergence of new challenges and interconnected risks.

**Case 1: Local Optimization**

Many highly industrialized countries of the world are primarily focused on optimizing marine spatial planning while mitigating the inherent conflict potential related to different overlapping ocean claims. An illustrative example is the North Sea and Skagerrak management area around the southern tip of Norway. It is



**Figure 2. The Blue Acceleration**

Global trends in (A) marine aquaculture production; (B) deep offshore hydrocarbon production, including gas, crude oil, and natural gas liquids below 125 m; (C) total area of seabed under mining contract in areas beyond national jurisdiction; (D) cumulative contracted seawater desalination capacity; (E) accumulated number of marine genetic sequences associated with a patent with international protection; (F) accumulated number of casts added to the World Ocean Database; (G) container port traffic measured in Twenty-Foot Equivalent Units (TEU); (H) total length of submarine fiber optic cables; (I) number of cruise passengers; (J) cumulative offshore wind energy capacity installed; (K) total marine area protected; (L) total area of claimed extended continental shelf. See [Note S1](#) for details and data sources.

among the world's most heavily trafficked regions, its waters sustain major commercial fish populations, its coastline fosters globally important aquaculture and cruise tourism industries, and its seabed contains large oil and gas reserves.<sup>85</sup> Although the offshore hydrocarbon industry tops the list in economic terms, oil and gas operations are recognized to have the potential to have a negative impact on shipping, capture fisheries, tourism, and aquaculture.<sup>86</sup> In some cases, governance tools have been able to manage conflict risk. New traffic separation rules, for instance, have helped to minimize damage to fixed fishing gear and collisions between shipping and fishing vessels.<sup>86</sup>

A risk linked to local optimization efforts is the tendency for industries to embark on ambitious individual growth trajectories that threaten to collectively exceed the capacity of the ocean and result in the inequitable distribution of harms and benefits. The Norwegian government, for instance, is aiming for a 5-fold increase in salmon production by 2050,<sup>85</sup> although the aquaculture industry is already constrained by a lack of production spaces and the fishing sector is concerned about existing farming operations because of pollution, sea lice outbreaks, and escaped salmon mixing with wild populations.<sup>85,87</sup> Likewise,

Norway's cruise tourism industry has grown for the last 15 years at an annual rate of 9% and is preparing for a 5-fold increase in visitors by 2030.<sup>88</sup> Oil and gas production is expected to continue growing for the next 5 years, while in June 2019, floating offshore wind farms were proposed off the southern tip of Norway to quadruple the country's wind power capacity,<sup>89</sup> and in September 2019, massive sulfide deposits rich in metals and minerals were found on Norway's continental shelf.<sup>90</sup> Precautionary approaches by individual industries can reduce risk, but the saturation of ocean space and tendency toward optimization render such areas particularly vulnerable to shocks.<sup>3</sup>

### Case 2: New Frontiers

The race to claim the ocean is extending even to its most remote areas. Consider, for instance, the scaly-foot snail (*Chrysomallon squamiferum*), which was first discovered in 1999, named in 2015, and by July 2019 had already been placed on the Red List of Threatened Species by the International Union for Conservation of Nature.<sup>91</sup> Found more than 2,400 m beneath the ocean's surface, on just 3 deep-sea hydrothermal vent systems that collectively cover an area of 0.02 km<sup>2</sup>, the scaly-foot snail's future was deemed threatened when two of these vent systems

fell within exploratory mining leases granted by the International Seabed Authority (ISA) to Germany (2015–2030) and China (2011–2026) to mine seafloor massive sulfides, rich in gold, silver, copper, zinc, and lead.<sup>46,92</sup> The ISA's mandate is limited to managing the resources of the seabed beyond national jurisdiction and therefore does not extend to the third vent system located within the exclusive economic zone of Mauritius.<sup>92</sup> Because of its unique trilayered natural armor, the scaly-foot snail has been the focus of biomimicry research funded by the US Department of Defense,<sup>93</sup> and 118 sequences from its genome have been deposited in GenBank, an open-access database of nucleotide sequences that serves as a reference point for the biotechnology industry.<sup>94</sup>

The claims on the scaly-foot snail therefore extend from its surrounding habitat to its physical form and genetic information through to its own existence. This example illustrates several dynamics of the blue acceleration. All the metals found in seafloor massive sulfides can be mined on land, but demand for use in high-end electronics and a decline in the ore quality of land-based sources have caused the commodity values to rapidly increase since 2000 (e.g., gold, +454%; silver, +317%; copper, +360%; zinc, +259%; lead, +493%), making seabed mining a viable commercial prospect.<sup>95,96</sup> Contrary to the precautionary principle, exploitation is proceeding ahead of exploration,<sup>8</sup> with mining licenses granted prior to a consensus on how to mitigate environmental impacts of mining, and despite the three hydrothermal vent systems (Solitaire, Kairei, and Longqi fields) not yet having been studied in detail.<sup>92</sup> Finally, because of the placement of claims and the complexity of territorial boundaries, the survival of the scaly-foot snail moved within 5 years from a responsibility of the global community to the responsibility of three countries: China, Germany, and Mauritius.

### Case 3: Global Consequences

Local or regional claims can also generate global consequences. In the South China Sea, for example, competing territorial claims have been the focus of military activity and geopolitical concern. Sovereign rights over the sea's rich natural resources and fishing grounds are disputed by Brunei, China, Malaysia, the Philippines, Taiwan, and Vietnam. More than half of the world's fishing vessels operate in the South China Sea; it is a major node in the network of undersea telecommunication cables, and an estimated one-third of global maritime traffic passes through the region, carrying some USD 3.4 trillion in goods annually.<sup>97,98</sup> A spike in insurance costs or the rerouting of even a portion of this trade due to the risk of armed conflict would have far-reaching consequences for the global economy and international order.<sup>98</sup>

Looking beyond geopolitical conflicts, the situation has also had widespread ecological impacts. In recent years, satellite imagery has revealed the scale of land reclamation in the South China Sea to increase the size of existing islands or create new ones altogether.<sup>99</sup> One archipelago—alternately referred to as the Paracel, Hoàng Sa, and Xisha Islands—includes 130 coral islands and atolls with a land mass of 7.75 km<sup>2</sup>. Over the past decade, an additional 13 km<sup>2</sup> of land has been reclaimed across the archipelago, tripling its land area, and resulting in 20 habitable outposts with infrastructure such as wind turbines, helipads, and harbors.<sup>100</sup> Often militarized for strategic importance,

these outposts have also facilitated a range of other claims, including industrial fishing, scientific activity, and hydrocarbon exploration.<sup>101</sup> Large-scale land reclamation in the South China Sea could be contributing further to the regional decline of fish stocks, down by 70%–95% since 1950,<sup>102</sup> because of increased access to fishing grounds and modification of the island mass effect, whereby coral islands and atolls generate areas of high biodiversity and phytoplankton density.<sup>103,104</sup> The conversion of coral atolls to human settlements also coincides with the almost complete disappearance of seabirds from the archipelago, although it sits in the middle of the East Asian-Australasian Flyway, which includes the most threatened or near-threatened species of any of the world's migratory routes.<sup>105</sup>

### Unknown Consequences

As the ocean space becomes progressively saturated by different claims, interactions and conflicts among them intensify, paving the way for new risks to emerge and regime shifts to occur.<sup>106</sup> These large and abrupt transitions can have persistent consequences and exhibit cascading behaviors that have been likened to domino effects.<sup>107</sup> Because of their complex and non-linear nature, such risks are rarely accounted for in the pursuit of optimizing individual claims. This creates conditions for unknown thresholds to be crossed and suggests that, in an increasingly connected world, limits to the blue acceleration could be set by emerging systemic risks rather than predictable finite limits of ocean claims.<sup>3</sup>

The blue acceleration is also occurring within a highly dynamic and changing context.<sup>108,109</sup> Climate change is already driving fish species migrations to higher latitudes and into new jurisdictional areas,<sup>110</sup> forcing aquaculture to move where environmental conditions are more favorable,<sup>35</sup> and opening up new areas for claims to be made, such as drilling for hydrocarbons and new shipping routes as a result of the contracting Arctic ice sheet.<sup>111,112</sup> Likewise, changes in the geopolitical and governance landscape (e.g., China's maritime Belt and Road Initiative, renegotiations of the Antarctic Treaty) have the potential to dramatically reshape the blue acceleration. As opportunities arise and close in a rapidly evolving and unpredictable ocean context, the future will also require confronting claims that we know little about or that are yet to emerge (Box 2).

### Stewardship of the Anthropocene Ocean

A once-popular view that the ocean—unlike the continents—was simply too big to be affected by human actions has been replaced by the reality of the Anthropocene Ocean,<sup>124</sup> in which the ocean is neither “too big to fail nor too big to fix, it is too big to ignore.”<sup>125</sup> Although the relevance of the ocean for humanity's future is undisputed, addressing the diversity of claims, their impacts, and their interactions, will require effective governance.

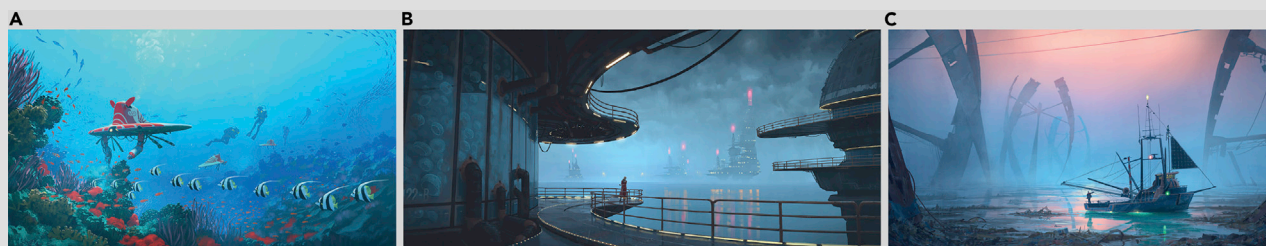
Numerous governance bodies and institutions exist with mandates and aspirations that could seem well-suited for navigating the blue acceleration (Table S3). Conservation and sustainable use of the ocean and its resources, for example, is a recurrent theme throughout the United Nations Convention on the Law of the Sea (UNCLOS), considered the Constitution of the ocean. Likewise, Sustainable Development Goal 14 is dedicated to Life Below Water and a commitment to “protect, and restore, the healthy productivity and resilience of oceans and marine

**Box 2. Envisioning Ocean Futures**

Anticipating how the blue acceleration will unfold presents a formidable challenge. Projecting the future of complex phenomena by extrapolating current trends is notoriously uncertain.<sup>113</sup> Highly unpredictable events are likely to occur,<sup>114</sup> while ideas, practices, and technologies that are marginal today may become dominant features of the future.<sup>115</sup> Consider, for instance, nascent phenomena such as floating cities,<sup>116</sup> autonomous maritime transport,<sup>117</sup> and underwater hydroponics<sup>118</sup> or data servers.<sup>119</sup>

Recent innovations in scenario planning can help deal with this uncertainty and complexity. A scenario is a plausible and simplified description of how the future could develop, based on a coherent and consistent set of assumptions about key driving forces and their relationships. Although the majority of marine scenarios have focused on climate change and the associated oceanographic and ecological consequences,<sup>11</sup> we argue that the challenges posed by the blue acceleration require more creative and dynamic ways of envisioning the future. Science-fiction prototyping methods, for example, have been applied to explore radical ocean futures that incorporate major surprises (e.g., tipping points) and involve co-evolutionary dynamics of integrated social-ecological systems.<sup>120</sup>

Participatory scenarios are another tool that has been used to identify and analyze the role of existing, but currently marginal, drivers of change in shaping the future.<sup>121,122</sup> However, most of this work has been conducted in the terrestrial domain. Applying participatory scenarios to the ocean, therefore, holds great potential for bringing about novel transformative pathways toward improved ocean governance and sustainability. Importantly, the inclusion of diverse stakeholders in the process of scenario creation can foster collective action to achieve common goals.<sup>123</sup> In the context of the blue acceleration, this means co-producing scenarios with a broad coalition of actors from industries, governments, local communities, non-governmental organizations, financial institutions, and natural resource managers. Such approaches would improve our collective capacity to not only envision but also shape a more sustainable and equitable future ocean.



The figure displays illustrations of three ocean scenarios developed in Merrie et al.<sup>120</sup> by applying science-fiction prototyping to incorporate and extrapolate from existing marine environmental, technological, social, and economic trends: (A) Oceans back from the brink, (B) FISH Inc., and (C) Rime of the last fisherman. Read the stories at [www.radicaloceanfutures.earth](http://www.radicaloceanfutures.earth). All images are copyright of Simon Stålenhag and reproduced with permission.

ecosystems to maintain their biodiversity, enabling their conservation and sustainable use for present and future generations [...] to deliver on all three dimensions of sustainable development.”

Yet cumulative human impacts on marine ecosystems have continued to increase across most of the ocean.<sup>10</sup> UNCLOS, its implementing agreements, and associated sectoral bodies, as well as coastal states, which are granted broad autonomy over the management of marine resources within their jurisdictions, have all struggled to realize this balance of conservation and sustainable use. For instance, the proportion of commercial fish stocks that are overfished has tripled over the past 40 years,<sup>25</sup> and competing claims over maritime territory and fishing quotas have resulted in conflicts for which traditional governance has proven poorly adapted.<sup>126</sup> Despite becoming the first of the Goals to have its own exclusive international conference, recent policy surveys also indicate that Goal 14 is systematically the least prioritized,<sup>127</sup> regardless of the nature of the respondents (e.g., government, development partner, private sector, non-governmental organization) and although reaching its targets would carry substantial co-benefits for achieving many of the other Goals.<sup>128</sup>

An additional hurdle for ocean governance is that almost two-thirds of the ocean lies beyond national jurisdiction, where activ-

ities are governed by a patchwork of sectoral organizations.<sup>129</sup> Notable governance gaps include the lack of a mechanism to create marine protected areas and the absence of regulations on access to marine genetic resources or the definition of subsequent benefit-sharing obligations.<sup>129</sup> International negotiations aimed at closing these and other governance gaps for biodiversity in areas beyond national jurisdiction (BBNJ) have been underway since 2005, with the prospect of a final agreement entering into force still years away. However, the UN General Assembly decision to narrowly define the mandate of the BBNJ negotiations and to bar negotiators from “undermining” the mandate of existing sectoral bodies raises questions about the extent to which any eventual treaty will affect the blue acceleration. The slow pace of international policy making also suggests that few new legal tools will be available in the near future to steer the blue acceleration toward more sustainable trajectories.

With the UN Decade of Ocean Science for Sustainable Development set to begin in 2021,<sup>130</sup> we call attention to four future challenges for the academic, policy, and practice communities. First, although the ocean is often considered a single unit in both aspirational and cautionary narratives, it is highly heterogeneous from biophysical, social, and legal perspectives. Confronting the

challenges associated with the blue acceleration therefore requires improved knowledge on where the claims are being made, the extent of resources available, and the stakeholders that will be affected. The framework we present here provides a systemic view of multiple ocean claims and trends over time, but corresponding analyses of their interactions, possible trade-offs, and social-ecological consequences remain to be done. This would allow for the mapping of areas of potential overlap and help inform the design of integrated governance structures, such as dynamic marine spatial planning.<sup>131</sup>

Second, greater attention should be directed to the actors placing the claims. Previous investigations have documented a high degree of consolidation among nations and companies involved in the global seafood industry<sup>132,133</sup> or in the patenting of marine genetic resources.<sup>38</sup> Identifying and engaging key corporate actors behind ocean claims would allow capitalizing on the increasing appetite of the private sector to consider biosphere stewardship.<sup>134,135</sup> A reflection of this is the expanding universe of sector-specific industry-led voluntary initiatives (Table S3) and initial efforts to encourage cross-sectoral engagement, as seen for instance in the UN Global Compact Sustainable Ocean Business Action Platform.<sup>136</sup> Although the effectiveness of such voluntary environmental programs is contingent among other things on rigorous monitoring and sanctioning mechanisms,<sup>137</sup> it is unclear how representative they are with regard to the actors of the blue acceleration. Their voluntary nature also underscores the need for more research to ensure that industry initiatives and voluntary programs contribute to evidence-based decision making that explicitly addresses social inclusion and equitable outcomes.<sup>138,139</sup>

Third, a focus on who and what is financing the blue acceleration could unlock powerful leverage points.<sup>140,141</sup> Incorporating more stringent sustainability criteria into ocean finance, be it from governments,<sup>142</sup> philanthropies,<sup>143</sup> insurance brokers,<sup>144</sup> banks or stock exchanges,<sup>141</sup> would redirect capital toward improved practices and accelerate action for a sustainable ocean economy. Blue bonds and other impact investment tools have emerged in recent years, but they represent only a small portion of financial flows. Although The Principles for Responsible Banking<sup>145</sup> or The Sustainable Blue Economy Finance Principles<sup>146</sup> suggest that the financial sector is starting to embrace its potential to steer businesses toward sustainability, operationalizing the principles remains a challenge. As pressures on the ocean mount, systematic social and ecological screening needs to become the norm for mainstream financial mechanisms (e.g., credit lending), in the same manner as is currently the case for financial auditing.<sup>141</sup>

Fourth, concerns have been raised over who is to gain from the blue acceleration. Benefits disproportionately flow to economically powerful states and corporations, whereas harms are largely affecting developing nations and local communities.<sup>139,147,148</sup> The vulnerability of small-island developing states and least-developed countries to the impacts of climate change faces the risk of being further augmented. Consequently, a growing number of studies are highlighting the need for social and equity issues to be considered on par with environmental concerns in discussions about ocean futures.<sup>21,139,147,149</sup> Navigating the blue acceleration in a just and sustainable way requires a particular emphasis on the equity implications of

increased ocean use across the globe, and how these multiple claims could have an impact on the economic safety and well-being of vulnerable communities and social groups.

## Conclusion

The opportunistic nature of human enterprise has continuously pushed the frontiers of exploration, responding to demand and outpacing regulatory changes, often at the expense of local communities and the environment. From the shoreline to the deep sea, the blue acceleration is already having major social and ecological consequences. Safeguarding ocean sustainability in times of rapid change will require transdisciplinary efforts to guide the activities and incentives of governments, corporations, and civil society toward ocean stewardship.<sup>150</sup> Should governance mechanisms succeed in connecting the momentum and aspirations of the blue acceleration to norms of equity, conservation, and sustainable use, this new phase of humanity's relationship with the biosphere can present a unique opportunity.

## SUPPLEMENTAL INFORMATION

Supplemental Information can be found online at <https://doi.org/10.1016/j.oneear.2019.12.016>.

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## AUTHORS CONTRIBUTIONS

J.-B.J. and M.N. conceived the original idea. J.-B.J. collected the data and led the writing. All authors contributed to the development and writing of the paper.

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**One Earth, Volume 2**

**Supplemental Information**

**The Blue Acceleration: The Trajectory  
of Human Expansion into the Ocean**

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**Note S1. Multiple ocean claims and data collection methodology.** Claims were identified and categorised through a four-year-long iterative process, aimed at understanding ocean-based sectors of direct relevance for ecosystem sustainability, human well-being and economic growth. We started with well-known uses of the ocean (e.g., fisheries, shipping, oil and gas drilling, tourism), and progressively included additional sectors and uses of relevance. This process allowed for an iterative identification of claims and trends over time, using a snowball sampling methodology based on reviews of relevant academic and grey literature, consultations with interdisciplinary marine experts at scientific workshops and conferences, and engagements with ocean policymakers, environmental non-governmental organisations, and actors from the private sector. All claims identified were examined with a similar approach and clustered according to three fundamental needs for humanity: food, material and space. See Table S2 and Table S3 for a summary of key environmental impacts and current governance processes associated with each claim.

## 1. FOOD

### *Seafood*

Historically, the ocean has been an essential source of food for human societies through the provision of fish, shellfish, mammals, marine reptiles, seabirds and seaweed. Since the 1960s, rates of fish consumption have been increasing twice as rapidly as population growth and fish has become one of the most widely-traded food commodities. In 2017, global fish production reached an all-time high of 173 million tonnes – of which 88% were used for direct consumption<sup>1</sup>. Today, it is the world's fastest-growing food sector and by far the largest employer among ocean-based industries, providing millions of jobs and a vital source of proteins and micronutrients to billions of people<sup>2-5</sup>. Wild capture volumes increased rapidly during the post-war period, peaking around the late 1990s, and declining since then despite an escalation in global fishing effort and improved technology<sup>6</sup>. Industrial fishing has been reported to cover a spatial extent more than four times that of agriculture<sup>7</sup> (but see <sup>8</sup>), with fish being caught at greater depths<sup>9</sup> and farther distances<sup>10</sup>. Future potential for increasing harvest lies in better management of stocks<sup>11</sup> and the exploitation of untapped resources, such as lower trophic levels or mesopelagic stocks<sup>12,13</sup>. In parallel, the farming of aquatic organisms dramatically increased over the last few decades and is now widely seen as a major component for future food security<sup>14</sup>. Since 1970, aquaculture production grew at an average annual rate of 8% worldwide, exceeding the growth rate of any other food production system<sup>15</sup>. While freshwater species account for most of the production and a large share of it still takes place inland<sup>1</sup>, the vast amount of space suitable for marine aquaculture in coastal and offshore areas presents great potential for expanding ocean aquaculture, once current limitations of aqua-feed supply and regional socio-economic and technological capacity are overcome<sup>16-19</sup>.

We used the FAO dataset FishStatJ to extract the global marine capture and aquaculture production (in tonnes) from 1970 to 2017 (<http://www.fao.org/fishery/statistics/>, accessed 13 April 2019). Global capture production was filtered by 'fishing area' to exclude inland capture. Similarly, global aquaculture production was filtered by 'environment' to exclude freshwater and brackish water production. The FAO global marine capture data represent a conservative estimate since they do not include unreported catch. See the Sea Around Us database for reconstructed estimates of both reported and unreported catch data (<http://www.seaaroundus.org/data/>).

### *Feeds and nutraceuticals*

Although the vast majority of fisheries products are used for direct human consumption, a substantial share indirectly contributes to human nutrition when utilized as feeds for the aquaculture and livestock industries<sup>20-22</sup>. Fishmeal and fish oil are key ingredients in animal feeds and are mainly produced

through the capture of feed-fish species that occupy low levels in marine food chains. For instance, most Peruvian anchoveta (*Engraulis ringens*) – often the world’s largest fishery – are reduced to provide fishmeal and fish oil for export<sup>23</sup>. The pet food industry also represents a vibrant and growing market for the fishmeal and fish oil sector<sup>24</sup>. Overall, a recent analysis estimated that 27% of reconstructed marine fisheries landings from 1950 to 2010 were destined for uses other than direct human consumption<sup>25</sup>. Besides, there is a rapid expansion in the range of ocean products used as nutraceuticals<sup>26,27</sup>. Combining the terms ‘nutrition’ and ‘pharmaceuticals’, nutraceuticals are foods containing bioactive molecules with health benefits that extend beyond nutritional value. Marine nutraceuticals represent an increasingly large portion of the global nutraceutical market (expected to reach around USD 385 billion by 2020)<sup>27</sup>, with products such as omega-3 fatty acids driving substantial investments in krill fisheries<sup>28</sup> as well as interests in largely untapped fish populations like lanternfish<sup>29</sup>.

## 2. MATERIAL

### *Hydrocarbons*

Fossil fuels account for more than three-quarters of the world’s primary energy use. Driven by growing demand but dwindling land-based resources, offshore extraction is rapidly increasing and represents about 30% of current global oil and gas production. Nearly 70% of the major discoveries of hydrocarbon deposits between 2000-2010 happened offshore and further reserves are suspected to exist in the deep-sea<sup>30</sup>. With more than 9,000 offshore platforms in service worldwide and one-third of the total value of the ocean economy, the oil and gas sector is the largest ocean-based industry<sup>3</sup>. As shallow-water fields become depleted and novel technologies emerge, production is moving towards greater depths and new territories, including the Arctic where vast undiscovered oil and gas reserves are expected<sup>31</sup>. The ocean floor also contains vast quantities of natural gas hydrates<sup>32</sup>. These ice-like solid compounds exist worldwide and may represent twice as much organic carbon as the world’s coal, oil and other forms of natural gas combined<sup>33,34</sup>. Owing to their immense energy content and the promise of energy independence they hold for some countries (e.g., Japan), natural hydrates have become attractive and experimental drilling is moving forward<sup>35</sup>.

Global offshore production of gas, crude oil and natural gas liquids in million barrels per day from 1950 to 2018 were extracted using the UCube database from Rystad Energy (<https://www.rystadenergy.com/>, accessed 17 April 2019) and divided by water depth groups: shallow (<125m); deepwater (125-1500m) and ultra-deepwater (>1500m).

### *Minerals*

Marine mineral resources are accumulations of minerals that form at or below the seabed and from which metals, minerals, elements, or aggregates might be extracted<sup>36</sup>. Natural aggregates, such as sand and gravel, are today the most mined minerals in the marine environment. Although sand used to be extracted mostly in land quarries and riverbeds, a shift to marine aggregates has occurred to satisfy the growing demand for construction materials required to build cities and develop transport infrastructures<sup>37,38</sup>. Aggregates are also increasingly dredged for land reclamation, coastal defence and beach replenishment projects<sup>39,40</sup>. Other resources currently mined from shallow water include placer deposits of diamonds, tin, titanium and gold<sup>36</sup>. However, rising demand for metals to sustain the development of high-technologies has led to a recent surge of interest in minerals from the deep sea<sup>34,41-43</sup>. The three major minerals considered of commercial interest are the polymetallic manganese nodules, polymetallic massive sulphides and cobalt-rich ferromanganese crusts. Compared to land deposits, little effort is needed to expose the mineral in deep-seabed deposits and less ore is needed to provide the same amount of metal due to the higher grade of marine resources<sup>36</sup>. Although deep-sea

commercial activity remains in its infancy and the regulatory framework is still under development, more than 900,000 km<sup>2</sup> have been estimated to be under exploration contracts in areas of national jurisdiction<sup>43</sup>. Beyond national jurisdiction, mineral-related activities fall under the International Seabed Authority (ISA) which, so far, has granted 30 exploration licences encompassing over 1.3 million km<sup>2</sup>.

Information on the area associated with each of these licences was obtained from ISA (<https://www.isa.org.jm/>, accessed 17 August 2019) and used to compile the cumulative area of seabed under contract in areas beyond national jurisdiction. Note that this remains an underestimate of the total area opened for mineral exploration since each contract for polymetallic nodule exploration also sets aside an equivalent area for use by the ISA itself or by developing states<sup>44</sup>.

### ***Desalinated water***

Desalination – the process of removing salt from water – has gained a lot of attention in the context of escalating water scarcity due to population growth, urban development (primarily in coastal areas) and climate change (increasing the frequency and severity of droughts)<sup>45,46</sup>. Used for drinking, sanitation and irrigation purposes, desalinated water is becoming an essential source of freshwater for nations and cities. For example, desalination provides Qatar with 99% of its drinking water<sup>47</sup> and the city of Cape Town has opened its first seawater desalination plants early 2018 in the aftermath of three years of droughts<sup>48,49</sup>. Desalination facilities worldwide now include about 16,000 operational plants with a global capacity of more than 95 million cubic metres per day (m<sup>3</sup>/d)<sup>50</sup>. Desalination of seawater accounts for the largest volume (59%), followed by brackish water (21%) and other less saline feedwater. New ocean-water desalination projects are on the rise, including floating desalination plants constructed on ships and offshore structures, which present the advantage of being mobile<sup>51</sup>.

We used the DesalData database from Global Water Intelligence (<https://www.desaldata.com/>, accessed 30 May 2019) to compile the cumulative annual new contracted desalination capacity (m<sup>3</sup>/d) worldwide from 1970 to 2018. The database was filtered by raw water type to retain only ‘seawater’, defined by a concentration in total dissolved salts between 20,000 and 50,000 parts per million. All other data set parameters (e.g., plant status, country, desalination technology) were kept at ‘any’.

### ***Ornamental resources***

Marine organisms have long been traded as ornamentals and currently supply three main markets: the home decor, the jewellery industry and the aquarium trade<sup>52</sup>. The trade of live marine organisms for aquaria is said to have started in Sri Lanka in the 1930s, before expanding during the 1950s when more places (e.g. Hawaii, the Philippines) began to issue permits for the collection of fish species<sup>53,54</sup>. Since then, it has grown into a major global industry thanks to the modernisation of air transportation, changes in economic livelihoods and the advent of new technology to maintain species in captivity<sup>55</sup>. Today, millions of marine organisms are removed from the ocean every year and inserted into private and public aquaria worldwide. The marine aquarium trade is worth several hundred million dollars and involves the collection of over 1,800 species of fish – and hundreds of species of corals and invertebrates – from more than 40 countries<sup>56</sup>. Unlike freshwater species that are mostly farmed, nearly all marine specimens are wild-caught, primarily from coral reefs<sup>54</sup>. In recent years, aquarium hobbyists have shifted their preferences from fish-only tanks to miniature reef ecosystems, further increasing demand for a variety of species<sup>57</sup>. However, the complexity of the industry and the lack of traceability protocols prevent reliable estimates of the volumes traded globally<sup>52</sup>.

### ***Genetic resources and derived products***

Since the first compounds were extracted from the Caribbean marine sponge *Cryptotethya crypta* in the early 1950s, the biodiversity of the ocean has held great promise for medical and industrial applications<sup>58–61</sup>. Commercial uses of genetic resources are closely linked to, and in many cases reliant upon, the non-commercial research that has generated vast databases of genetic sequence data, with today the identification of over 34,000 natural products from species found in the ocean (<http://pubs.rsc.org/marinlit/>). Marine organisms are of particular interest for bioprospecting since many have evolved to thrive under extreme conditions of pressure, temperature, salinity or darkness, making their genetic code the subject of great commercial interest for a wide range of industries (e.g., pharmaceuticals, nutraceuticals, cosmeceuticals, chemicals)<sup>62,63</sup>. One illustration of this trend is the growth in the number of patent claims associated with genes of marine organisms<sup>63–65</sup>. As of August 2018, 13,171 genetic sequences from 865 marine species had been associated with patents with international protection filed under the Patent Cooperation Treaty<sup>66</sup>.

Data on the accumulated number of marine genetic sequences associated with a patent from 1988 to 2018 were retrieved from Blasiak et al.<sup>66</sup> based on publicly available records of the patent division of GenBank from the National Center for Biotechnology Information (<ftp://ftp.ncbi.nih.gov/genbank/>, accessed 08 August 2018).

### ***Intangible material: scientific information***

The ocean offers an immense source of knowledge for future discoveries and understanding of the world. Yet much of the deep-sea environment remains unexplored<sup>67</sup> and only 16% of all named species are marine, although the rate of their discovery has been higher than terrestrial ones since the 1950s<sup>68,69</sup>. The advent of technologies such as satellite imagery, DNA sampling, and remotely operated vehicles are opening up new frontiers for marine research and leading scientists to urge for ‘exploration before exploitation’. Indeed, only 5% of the seafloor has been mapped in the level of detail equivalent to the high-resolution maps of the Moon and Mars<sup>70</sup>. At the same time, novel technologies have contributed to sequencing costs dropping by four orders of magnitude over just the past 10 years<sup>71</sup>, spurring tremendous progress in our understanding of marine taxonomic diversity. More than ever before, and across a broad range of disciplines, the marine scientific community has become an important stakeholder in the ocean<sup>72,73</sup>.

One illustration of this growing body of scientific information is the amount of data flowing into the World Ocean Database (WOD; <https://www.nodc.noaa.gov/>). The WOD is the world’s largest publicly available, uniform format quality-controlled global ocean profile dataset, containing nearly 16 million oceanographic casts – where ‘cast’ refers to an oceanographic profile or set of profiles collected concurrently at the same location from the same set of instruments<sup>74</sup>. We used the accumulated number of casts, from all instrument types, added every year from 1970 to 2019 to the WOD, courtesy of NOAA/NCEI World Ocean Database.

## **3. SPACE**

### ***Shipping***

From the spread of ideas and human settlements to early trade routes and globalisation, ocean shipping has been of paramount importance for the development of civilisation. The introduction of container shipping in the late 1960s revolutionised maritime transport and has triggered an unprecedented surge in the industry over the last 50 years<sup>75</sup>. In 2018, the world’s commercial shipping fleet consisted of 94,171 vessels, accounting for over 80% of global trade by volume and more than 70% of its value<sup>76,77</sup>. Today, although the increase in frequency and intensity of storms associated with sea-level

rise may disrupt maritime transport, climate change is also leading to the emergence of new trade routes that reduce shipping distances and travel times<sup>78-80</sup>. The decline in sea ice concentration has been associated with increased traffic across the Canadian Arctic Archipelago<sup>81</sup>, and the possibility of connecting Northwestern Europe to East Asia through the Arctic Ocean is gathering strong economic interest<sup>80</sup>. Maritime traffic is therefore predicted to keep increasing in the coming years and ocean shipping to remain the most important mode of transport for international merchandise trade<sup>77</sup>.

We compiled data on global container port traffic (measured in TEUs) from 1974 to 2017. TEU stands for Twenty-Foot Equivalent Unit which corresponds to the dimensions of a standard shipping container and is used to measure a ship's cargo carrying capacity. Data for the period 1974-1996 were based on Containerisation International Yearbooks and retrieved from McCauley et al.<sup>44</sup>. Data for 2000-2017 were obtained from the World Bank

(<https://data.worldbank.org/indicator/IS.SHP.GOOD.TU>, accessed 15 April 2019).

### ***Pipelines and cables***

Submarine pipelines are used to carry substances such as gas, oil, water or sewage. Since the first deployment in the early 1950s, oil and gas pipelines have rapidly expanded worldwide to keep up with the development of the offshore hydrocarbons industry. No reliable global data on the total length of undersea pipelines are available but it is estimated that well over 100,000 km have been deployed<sup>82</sup>. In the Gulf of Mexico alone, more than 72,000 km of pipelines have been installed since 1952<sup>83</sup>. The world's longest offshore pipeline is found in the Baltic Sea, carrying natural gas from Russia to Germany over 1,224 km<sup>84</sup>. The first submarine communication cable was laid between France and England in 1850. It was telegraphic and had a capacity of 10 words per minute<sup>85</sup>. More than a century later, in 1988, the first fibre optic cable was deployed across the Atlantic, marking the beginning of what would become the backbone of the global internet<sup>86</sup>. Today, 99% of international telecommunications is carried over 1.3 million km of undersea cables, offering more reliability, speed, capacity and cost advantages than satellite communications<sup>87</sup>. Submarine cables are also considered an essential infrastructure for sustainable development due to the social-economic benefits they bring to the world while having minimal ecological footprint<sup>88</sup>. Faced with the ever-increasing amount of data and people online, new submarine cables are continuously planned to meet the demand for higher bandwidth and ensure a stable global broadband network.

Data on the total length (kilometres) of submarine fibre optic cables deployed every year from 1989 to 2018 were extracted from the 6<sup>th</sup> and 7<sup>th</sup> issues of Submarine Telecoms Forum's Annual Industry Report<sup>87,89</sup>.

### ***Tourism and recreation***

Marine and coastal tourism encompasses all ocean-related tourism and leisure activities that take place in coastal areas and the offshore waters such as recreational boating and fishing, swimming, snorkelling, diving or cruise shipping<sup>90</sup>. It is one of the fastest-growing sectors of the world's tourism industry, providing livelihoods and income for millions of people in coastal communities<sup>3,90</sup>. According to the OECD's Ocean Economy Database, maritime and coastal tourism accounts for about 26% of total value added of the ocean-based industries and is the second-largest employer in the ocean economy<sup>3</sup>. Driven by ageing populations, higher incomes and upward consumption trends, ocean tourism is expected to develop even more in the coming years. Cruise shipping, for instance, is the fastest-growing segment of the leisure travel industry<sup>91</sup> and has seen a staggering 52-fold increase in the annual number of passengers since 1970. Growing demand from emerging economies as well as the opening of Arctic seas during summer months are likely to reinforce this trend<sup>92</sup>.

Multiple sources were used to compile data on the global annual number of cruise passengers from 1970 to 2018 based on the best available information. According to Honey and Krantz<sup>91</sup>, half a million passengers took a cruise in 1970. Ten years later, in 1980, there were 1.4 million passengers<sup>93</sup>. Data for the period 1993-2018 were obtained from G.P. Wild (International) Limited, courtesy of Peter Wild.

### ***Land reclamation***

Land reclamation is an ancient practice that consists in creating new land by raising the elevation of the seabed or pumping water out of wetland areas. As populations, economies and cities keep expanding in coastal areas, it has become a critical feature of littoral development to resolve land shortages and accommodate the increasing need for urban and industrial spaces<sup>94,95</sup>. Land reclamation is commonly used for port expansion, industrial areas, airport runways, agriculture, residential areas and strategic military zones<sup>96</sup>. Iconic examples include the Palm Islands in Dubai, Dutch polders, Kansai Airport in Osaka Bay, as well as artificial islands recently built in the South China Sea to assert sovereignty in a context of intense geopolitical tensions<sup>97</sup>. Global data on annual area reclaimed overtime is not available but a recent analysis of satellite imagery estimated that 33,700 km<sup>2</sup> of land have been added in coastal areas over the last 30 years<sup>98</sup>. China, in particular, is leading the world in large scale reclamation projects, extending its coastline by hundreds of square kilometres every year<sup>99,100</sup>.

### ***Renewable energies***

Faced with the urgency of reducing carbon emissions under increasing global energy demand<sup>101</sup>, marine renewable energies are amongst the solutions with the greatest potential<sup>102-104</sup>. They include energy derived from wind, waves, currents, tides, salinity gradients, thermal gradients and marine biomass<sup>105</sup>. Although the combined exploitation of several of these (e.g., offshore wind and wave energy) holds great promise<sup>103</sup>, marine wind power is the only one so far to have been commercially deployed at a large scale, driven by greater productivity potential, space constraints on land, technological innovations and increasing demand for electricity in coastal regions<sup>106,107</sup>. Since 1991, when the first commercial wind farm was set up in Denmark, the offshore wind industry has achieved a cumulative global installed capacity of 23,350 megawatts (MW), of which 79% is located in European waters. While the majority of turbines have been installed close to shore, recent studies indicate the potential of even greater wind power generation over open ocean areas, foreshadowing the prospect of deepwater installations as the next frontier<sup>108,109</sup>.

We used data from the International Renewable Energy Agency (<https://www.irena.org/en>, accessed 13 April 2019) to obtain the offshore wind energy capacity (MW) installed worldwide from 2001 to 2018. Before 2001, there were only three countries with offshore wind farms: Denmark, Sweden and the United Kingdom. Web searches were conducted to find the installed capacity in these countries during the period 1991-2000 based on national statistics.

### ***Geoengineering***

Defined as ‘the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change’<sup>110</sup>, geoengineering is said to become implicitly embedded in international climate change policy<sup>111</sup>. Yet it has been, and still is, much debated among ocean and climate scientists<sup>112,113</sup>. In contrast to terrestrial proposals that are often limited by unrealistic land requirements, ocean geoengineering was proposed already in the late 1980s as a way to sequester carbon from the atmosphere and enhance the Earth’s albedo<sup>111,114</sup>. In particular, ocean fertilization (i.e.

increasing the supply of nutrients to enhance biological productivity) and the sequestration of carbon dioxide in sub-seabed areas have been experimentally studied or even deployed on a small scale<sup>115–117</sup>. Whether such approaches will ever provide realistic and sustainable solutions at larger scales remains to be seen.

### ***Waste disposal***

Ocean dumping of industrial wastes, chemicals, munitions or radioactive materials was common practice until the 1972 London Convention and 1996 London Protocol drastically regulated the disposal of waste at sea<sup>118</sup>. For instance, hundreds of thousands of containers of radioactive materials were dumped from 1946 through 1993<sup>119,120</sup>. Today, the vast majority of reported dumping consists of dredged material in addition to fish waste and human-made structures (sometimes intended to create artificial reefs). However, uncertainties remain as to the real extent and nature of ocean waste disposal given the lack of information and that some of the world's largest economies are still not party to any of these international agreements<sup>121</sup>.

### ***Conservation***

The creation of marine protected areas (MPAs) has been described as ‘one of the most practical and cost-effective strategies in ocean conservation’<sup>122</sup>, whose benefits are expected to offer a wider array of ecological, social and economic contributions than just nature conservation<sup>123</sup>. In line with the United Nations Sustainable Development Goals and Aichi Biodiversity Target 11 of the Convention on Biological Diversity, coastal states have committed to protecting at least 10% of the marine environment by 2020. Yet scientists and non-governmental organisations have called for a more ambitious coverage of at least 30%<sup>124,125</sup>. Progress toward these targets has accelerated over the last few years, with more than 16,500 MPAs covering 7.5% of the ocean<sup>126</sup>. While this trend was marked by the recent designation of very large MPAs (>100,000 km<sup>2</sup>), virtually all of the growth has remained focused on national waters and only 1.2% of the areas beyond national jurisdiction is currently under some protection<sup>126</sup>.

We used the World Database on Protected Areas (<https://www.protectedplanet.net/>, accessed 15 April 2019) to quantify the cumulative annual marine area protected globally in square kilometres from 1970 to 2018, based on the GIS areas calculated by the WDPA team in the Mollweide projection<sup>127</sup>. Only marine and coastal protected areas with the status ‘designated’ (i.e., recognized or dedicated through legal means, which implies specific binding commitment to conservation in the long term) or ‘inscribed’ (i.e., designated under the World Heritage Convention) or ‘adopted’ (i.e., designated as Specially Protected Area of Marine Importance under the Barcelona Convention) and for which the status year was available were considered. In case of coastal protected areas (partially marine and terrestrial), only the marine area was accounted for.

### ***Territorial boundaries***

The United Nations Convention on the Law of the Sea (UNCLOS) was adopted in 1982 and came into force in 1994, providing the foundations for maritime jurisdiction and legal zoning (Figure S3). Coastal states are entitled to full sovereignty over their territorial waters that extend 12 nautical miles (22 km) from the coastline. Beyond and adjacent to the territorial sea, lies the exclusive economic zone (EEZ), up to 200 nautical miles (370 km) from shore. Within the EEZ, a state has rights to explore and exploit natural resources in both the water column and the seabed and subsoil (i.e., the continental shelf). When the distance between two state coastlines is less than 400 nautical miles, it falls upon the respective countries to define the actual maritime boundary. Prominent disputes include the Spratly Islands in the South China Sea<sup>128</sup> and the question of international waters in polar

regions<sup>129</sup>. Depending on the recognition, or not, of some of the disputed jurisdictional claims, the global area falling within EEZ represents between 36-42% of the ocean. The rest is subject to international law and commonly designated as the High Seas (i.e. the water column) and the Area (i.e., the seabed and subsoil). However, if a coastal state is able to provide scientific evidence that the continental shelf naturally extends beyond the country's EEZ, it is allowed under Article 76 of UNCLOS to claim an extended continental shelf – up to 350 nautical miles (648 km) from shore or 100 nautical miles seaward (185 km) from the 2500 m isobath – giving the country exclusive rights to further explore and exploit the seafloor<sup>130,131</sup>. Submissions are received by the UN Commission on the Limits of the Continental Shelf, made up of 21 geologists, geophysicists and hydrologists who are responsible for reviewing the data and providing recommendations on the outer limits<sup>132</sup>. As of June 2019, 84 submissions by 71 countries (with an additional 19 preliminary information from 12 countries) had been received, representing a combined area of approximately 37.2 million km<sup>2</sup> of seafloor claimed.

We used the official list of submissions (n=84) to the UN Commission on the Limits of the Continental Shelf ([http://www.un.org/depts/los/clcs\\_new/commission\\_submissions.htm](http://www.un.org/depts/los/clcs_new/commission_submissions.htm), accessed 17 June 2019), which does not include preliminary submissions due to their incomplete nature. The approximate area in square kilometres associated with each submission was obtained from the Fugro Global Law of the Sea Database (as of June 2019), courtesy of Robert van de Poll<sup>133</sup>. The total annual area claimed overtime was compiled based on the date of submission. The shapefile of claimed extended continental shelves was created by combining information from UNEP ([www.continentalshef.org](http://www.continentalshef.org)) and coordinates of the most recent submissions. The shapefile of exclusive economic zones was retrieved from [www.marineregions.org](http://www.marineregions.org).

### ***Military activities***

The use of the seas for military purposes involves the development of airborne, surface, and submarine military power for war-fighting and peace-keeping operations. Activities include naval exercises, law enforcement, task force manoeuvring, weapon testing, intelligence collection and surveillance, as well as hydrographic surveys<sup>134</sup>. The number of navies has tripled since the end of the Second World War, with currently more than 160 navies across the world. This proliferation is unprecedented and a marked feature of the second half of the twentieth century<sup>135</sup>. Nations competitively use every aspect of sea power to promote their security and geopolitical influence<sup>136</sup>. While there have been few naval conflicts since 1945, and only the United States Navy has been able to truly operate globally, both China and Russia show strong maritime ambitions. The building of artificial islands to set up military bases in the South China Sea is one illustration of these aspirations. Technological innovations have also led to the emergence of more capable vessels and the growing reliance on advanced unmanned military devices. For instance, the Pentagon recently announced their intention to deploy a network of mini-depots at the bottom of the ocean, which could be commanded to deliver a wide range of drones to the sub-surface, surface, and air<sup>137</sup>.

**Table S1.** Examples of headlines capturing the diversity of hopes and expectations for the ocean.

<b>Headline</b>	<b>Source</b>
"Farming the ocean to save the world"	<a href="#">Quartz</a> (2018)
"Can the ocean feed a growing world?"	<a href="#">National Geographic</a> (2018)
"The future of fish farming lies out in the oceans"	<a href="#">Salmon Business</a> (2017)
"Marine algae could help feed the world"	<a href="#">World Economic Forum</a> (2017)
"Deepwater leads the way in oil, gas discoveries in 2019"	<a href="#">Oil Review Middle East</a> (2019)
"There's tremendous room for growth in offshore oil & gas"	<a href="#">Oil Price</a> (2019)
"Deep-sea mining to turn oceans into new industrial frontier"	<a href="#">The Guardian</a> (2019)
"The ocean could be the new gold rush"	<a href="#">National Geographic</a> (2016)
"Japan's grand plans to mine deep-sea vents"	<a href="#">BBC</a> (2019)
"The future of technology is hiding on the ocean floor"	<a href="#">Gizmodo</a> (2016)
"Electric car future may depend on deep sea mining"	<a href="#">BBC</a> (2019)
"Diamond mining companies setting sights on the sea as land dries up in Africa"	<a href="#">The Telegraph</a> (2016)
"Mining companies turning to the oceans for precious gems and metals"	<a href="#">The Weather Channel</a> (2016)
"A new frontier for diamond mining: the ocean"	<a href="#">The Washington Post</a> (2017)
"Biological bounty is the ocean's richest treasure"	<a href="#">Financial Times</a> (2019)
"Can ocean desalination solve the world's water shortage?"	<a href="#">ThoughtCo</a> (2018)
"Could seawater solve the freshwater crisis?"	<a href="#">National Geographic</a> (2011)
"Can the oceans solve water scarcity?"	<a href="#">Arab News</a> (2017)
"Oceans: Medicine chests of the future?"	<a href="#">The Scientist</a> (1999)
"Humanity's health may rely on what sits on the Arctic seabed"	<a href="#">BBC</a> (2016)
"Deep sea sponges may hold key to antibiotic resistance"	<a href="#">China Dialogue Ocean</a> (2019)
"Ocean medicine hunt: a Wild West beneath the waves?"	<a href="#">BBC</a> (2014)
"Why the ocean holds the key to sustainable development"	<a href="#">World Economic Forum</a> (2019)
"The quest to map the mysteries of the ocean floor"	<a href="#">BBC</a> (2018)
"Deep sea marine science is key to unlocking the potential of our oceans"	<a href="#">ISSD</a> (2019)
"China to develop Arctic shipping routes opened by global warming"	<a href="#">BBC</a> (2018)

“Google plans to expand huge undersea cables to boost cloud business”	<a href="#">The Wall Street Journal</a> (2018)
“The undersea cable market is booming again, this time funded by big tech”	<a href="#">Bloomberg</a> (2019)
“The cruise industry's boom is primed to continue”	<a href="#">Forbes</a> (2018)
“Tourists are turning to the ocean’s depths for adventure”	<a href="#">Business Destinations</a> (2018)
“The future of tourism is a \$20 million hotel that takes guests 30 feet underwater”	<a href="#">Business Insider</a> (2015)
“How artificial islands could help us adapt to climate change”	<a href="#">BBC</a> (2018)
“Crowded cities short on housing are looking to turn water into land”	<a href="#">Slate</a> (2019)
“Kiribati looks to artificial islands to save nation from rising sea levels”	<a href="#">ABC News</a> (2016)
“Floating cities could ease the world’s housing crunch, the UN says”	<a href="#">National Geographic</a> (2019)
“World's first floating city to be built off the coast of French Polynesia by 2020”	<a href="#">The Independent</a> (2017)
“Floating cities on the ocean might be the wave of the future”	<a href="#">INSH</a> (2017)
“Can deepwater wind farms power the world?”	<a href="#">USA Today</a> (2017)
“A new wave in renewables harnesses the power of the ocean”	<a href="#">Quartz</a> (2017)
“Blue energy: The marine renewables sector starts to show promise”	<a href="#">The Independent</a> (2017)
“The world’s first floating wind farm could be a game changer for renewable power”	<a href="#">Quartz</a> (2017)
“The entire world could be powered by a deep-sea wind farm, scientists find”	<a href="#">The Independent</a> (2017)
“Limitless wave power could cure our addiction to fossil fuels”	<a href="#">Wired</a> (2017)
“Look to the ocean for climate change solutions”	<a href="#">CNN</a> (2019)
“Adding iron to oceans could increase carbon storage”	<a href="#">Cosmos</a> (2019)
“Tackle climate change by fertilising ocean with iron, expert says”	<a href="#">The Independent</a> (2019)
“Marine protected areas for a sustainable future”	<a href="#">HuffPost</a> (2018)
“High Seas protections could help reverse loss of biodiversity”	<a href="#">The Pew Charitable Trusts</a> (2019)
“The race to conquer the Arctic – the world’s final frontier”	<a href="#">NewStatesman</a> (2018)
“The South China Sea will be the battleground of the future”	<a href="#">Business Insider</a> (2016)

**Table S2.** Summary of key environmental impacts associated with each ocean claim.

Claim	Impacts	References
Seafood	<p>The environmental footprints of both capture fisheries and aquaculture can vary significantly, depending on species targeted and production practices. Marine capture fisheries are responsible for the removal of large quantities of biomass and apex predators from marine food webs. This can result in trophic cascades, regime shifts and the erosion of genetic diversity, raising the risk of localised extinctions and decreasing the capacity of populations to adapt to changing climatic and ecological conditions. Gears employed in capture fisheries have considerable impacts on ecosystems and non-target species. For instance, bottom trawls severely disturb benthic communities; purse seines cause bycatch and catch of juvenile fish; and longline and driftnet fishing can likewise result in substantial seabird and marine mammal bycatch. Abandoned, lost and discarded fishing gear contributes to ocean plastic pollution, generating ‘ghost gear’ that entangle and kill a wide range of marine life. The carbon footprint of capture fisheries is also substantial due to fuel consumption. Mariculture activities can result in large scale coastal habitat modification and in the escapement of non-native and genetically-modified organisms, which subsequently mix and outcompete native populations. Parasites and pathogens have also crossed over to native populations, most notably perhaps in areas characterised by both wild salmon fisheries and farmed production. The overuse and inappropriate application of antibiotics contribute to the global spread of antimicrobial resistance, while excess pesticides, nitrogen and other byproducts pollute ecosystems locally.</p>	138–143
Feeds and nutraceuticals	<p>The large-scale removal of small pelagic feed-fish (e.g. sprats, sardines, herrings) impacts both their prey and predators, as well as bycatch populations. Localised overfishing of feed-fish species can change population structure resulting in genetic drift and reduced adaptive capacity. Feed-fish are primarily caught using seine nets, with generally minimal impact on the seafloor, low levels of discards, but high levels of bycatch. Small pelagics are also nutritionally rich and of crucial importance in the diets of some coastal populations, leading to criticisms of their capture for use in aquaculture production bound for export markets. The environmental impacts from marine nutraceuticals are poorly understood but involve removal of biomass from the ocean and corresponding disruption of food webs and marine ecosystems.</p>	29,144,145
Hydrocarbons	<p>Fossil fuels are the largest source of anthropogenic emissions of carbon dioxide. Noise caused by seismic surveys can disturb, injure or kill marine animals. Drilling operations result in toxic drilling mud and drill cuttings that contaminate benthic communities over many years. Drilling also brings to the surface what is known as ‘produced water’, a mixture of water containing high concentrations of heavy metals, radium isotopes and hydrocarbons. Oil spills and gas leaks occur at various stages of offshore production with negative impacts on the marine and terrestrial environments. While gas leaks can create anoxic zones, large oil spills represent a major threat to biodiversity with long-term effects on both deep-sea ecosystems and coastal habitats – even in areas far from the spill source due to winds and currents. Mobile infrastructures also constitute a vector for the introduction of non-native species (e.g., following the relocation of rigs between drilling locations). The prospect of extracting gas hydrates from the seabed comes with its own set of challenges, including</p>	30,33,146

	uncontrolled leakage of methane, seafloor subsidence, submarine landslides, and the dramatic increase in greenhouse gas emissions.	
Minerals	Ocean mining implies both physical and biological impacts. Modification of the seabed topography through suction or drilling can alter local current patterns, change the composition of sediments, and damage archaeological sites. Near-shore dredging of marine aggregates also accelerates beach erosion by reducing the sediment supply to the coast. Turbidity plumes generated by operations on the seafloor as well as the discharge of processed materials and waste-water at the surface impact ecosystems far beyond the mining area. The direct removal of substrata and associated seabed fauna and flora causes a net decline in species abundance and diversity. Noise, light and chemical pollution from mining vehicles further affect marine organisms. Concerns about how these impacts would unfold in the deep sea have escalated given the slow rate of growth and uncertain recovery of such ecosystems. Potential impacts on fragile hydrothermal vents, for instance, include habitat destruction, rare species extinction and modification of fluid flux regimes.	34,40,147,148
Desalinated water	Environmental concerns associated with desalination include the emission of greenhouse gases and air pollutants to generate the required energy, impingement and entrainment of marine biota during the intake of feedwater, and the discharge of concentrate and chemical residues to the marine environment. High salinity and elevated temperature in reject streams can be fatal to marine organisms and impair the functioning of coastal ecosystems. Desalination infrastructures may also alter sediment transport.	45,149
Ornamental resources	The marine aquarium trade has been criticised for destructive collection practices, overharvesting of fish and invertebrates, localised depletion of rare target species, and the release of non-native species to foreign habitats. The removal of live rock, which increases erosion and habitat loss, and the use of cyanide to collect fish are particularly damaging to fragile coral reef ecosystems from which most marine ornamental species are harvested.	53,54,57
Genetic resources and derived products	Due to recent advances in genomics and DNA sampling techniques, exploitation of marine genetic resources has limited effect on ocean ecosystems, even though the removal of biological material for bioprospecting purposes, including through the use of trawls or collection nets, can have minor destructive impacts. While the mass of biological material required for this work is usually small, harvesting of marine species for cosmeceutical applications has been linked in some cases to declining local populations.	147,150,151
Scientific information	The operation of marine research vessels and remotely operated vehicles (ROVs) is a comparatively minor contributor to anthropogenic emissions and pollution. Trawls, dredges, grabs and other repeated sampling apparatus can have a direct physical impact on deep-sea habitats. For instance, scientific research remains the primary source of human disturbance at hydrothermal vents, including light pollution from submersibles and ROVs. However, best practice sampling protocols and new autonomous vehicles have helped to eliminate uncontrolled specimen collection and minimise environmental impacts.	67,147,150,152
Shipping	Shipping represents a significant contributor to the emissions of pollutants and greenhouse gases such as sulfur and nitrogen oxides, carbon dioxide and particulate. Nearly 70% of ship emissions occur within 400 km of the shoreline, generating air	153–156

	<p>quality problems in coastal areas and harbours with heavy traffic. The growth of global shipping also leads to an increasing number of ship-strikes causing injury or death to marine megafauna. Underwater noise produced by vessels can disrupt the orientation, communication and feeding patterns of marine species. Additional impacts associated with marine transportation include the release of ballast water that can introduce potentially invasive species, oil and chemical spills, litter and sewage discharges, grounding and sinking damages, cargo losses as well as pollution from shipbreaking activities and use of antifoulants.</p>	
Pipelines and cables	<p>Offshore pipelines are either resting on top of the seabed or laid in a trench that can be filled or left open. Beyond relatively minor habitat disturbance, their biggest impact is through leakage of oil and gas due to damage from ships' anchors and fishing gear, corrosion, storms, or material failure. Pipelines also present pathways for invasive species through linear infrastructure and prevent bottom trawling and cable-laying activities. Underwater communication cables are usually buried (in shallow waters) or simply laid on the seabed (at greater depths). Neither the physical disturbance nor the associated noise of the laying process is likely to have a significant impact in the long term. Power cables carrying electricity emit heat and an electromagnetic field to which some species may be sensitive.</p>	30,146,157
Tourism and recreation	<p>The growth of tourism in coastal areas is driving the loss of natural habitats and the development of artificial shorelines with negative consequences for biodiversity. Hard coastal structures such as seawalls and groynes can also alter sand transport and sedimentation patterns. The spread of hotels, resorts and golf courses causes habitat destruction and pollution, while the influx of tourists inevitably results in problems in the treatment of sewage and solid wastes. Litter left on beaches by tourists, for instance, represents a significant source of marine debris. Cruise ships are another major source of garbage and wastewater, in addition to other shipping-related impacts. Both cruise ships and small recreational boats can cause damage to coastal ecosystems by anchoring in vulnerable habitats (e.g., coral reefs, seagrass beds) and by facilitating the transfer of invasive aquatic species. Recreational fishing also has some direct impact on marine biota, as does the overcrowding of tourists and divers through physical damage (including on cultural heritage) and disturbance of fish and other species.</p>	90,92,158
Land reclamation	<p>Land reclamation causes widespread ecological damage, including the loss of entire ecosystems such as vegetated coastal wetlands and coral reefs, ultimately leading to a substantial decrease in ecosystem functions and services. For instance, it is estimated that China has lost more than 50% of coastal wetland areas due to land reclamation. Building artificial islands can result in direct destruction of coral reefs, while the dredging and physical removal of seabed further affect marine life through turbidity plumes that reduce light penetration and decrease the photosynthetic activity of many organisms. Large-scale coastal reclamation also increases exposure to climate-induced disaster risks such as sea-level rise and storm surge.</p>	94,159
Renewable energies	<p>Ocean renewable energies provide a source of low-carbon electricity with no emissions of toxic air or water pollutants. The environmental footprint depends on the size of the installation and specific technology. Potential impacts include pollution and disturbance from increased maintenance vessel traffic, modification of local environmental conditions by changing energy states downstream, risks of collision with moving turbine blades, high levels of underwater noise and vibration, benthic</p>	105,160,161

	habitat degradation, species displacement and impaired visual amenity. Offshore infrastructures can also offer a base for the spread of invasive species. Submerged power cables carrying electricity to onshore stations emit heat and an electromagnetic field to which some species may be sensitive.	
Geoengineering	Due to insufficient or incomplete research, little is known about the potential benefits and risks associated with marine geoengineering. However, a range of undesirable effects has been considered in the literature. For instance, large-scale fertilization of the ocean could release climate-relevant gases (e.g., methane), cause eutrophication due to deep water nutrients coming to the surface, create low-oxygen zones, change ocean acidification patterns, increase toxic phytoplankton populations, and modify benthic and pelagic ecosystem structure. By altering biological communities, these changes would in turn likely affect fisheries.	113,115,116
Waste disposal	The dumping of munitions, radioactive materials, chemicals, and industrial wastes containing toxins such as mercury and PCBs used to be a major source of marine pollution. Dumped sewage sludge and animal slurry also contributed to eutrophication problems. Although most of it is now prohibited, some wastes (e.g., munitions) still present a risk for ocean activities like trawl fishing, cable laying and construction of offshore infrastructures. Today, the vast majority of reported dumping consists of dredged material that can smother the seabed and remobilise hazardous substances. Decommissioned and abandoned man-made structures (including platforms and vessels) are sometimes converted to artificial reefs.	121
Conservation	Marine protected areas are a key strategy for protecting biological resources and promoting adaptation to climate change, but they vary considerably in their effectiveness depending on monitoring and enforcement capacities. They can also have negative socio-cultural impacts on local communities such as conflict, displacement, change in livelihood, unequal distribution of benefits and restricted access to culturally important sites.	123,162,163
Territorial boundaries	Arbitrary territorial boundaries such as the 200 nautical miles of the exclusive economic zone have no ecological meaning and are often at odds with ecological connectivity. Environmental impacts resulting from sovereign claims over marine areas will depend on the specific activities conducted and the regulatory frameworks in place under this sovereignty.	164,165
Military activities	The military uses of ocean space result in a wide range of environmental impacts, including ecosystem loss, chemical contamination, noise pollution and invasive species transportation. The building of artificial islands for military bases, for instance, causes severe damage to the local environment, and so did the testing of nuclear weapons for many years. Wreckages from naval ships and dumped barrels of munitions and chemical warfare litter the ocean floor, preventing activities on the seabed and posing long-term risks once those begin to degrade and leak. Excessive noise from explosive detonations and sonar technologies used during naval exercises represents a major threat to marine species behaviour and communication patterns. The use of military sonar, in particular, has been associated with mass stranding mortality events in cetaceans. Both aircraft and ships have also been implicated in the introduction of invasive species to remote oceanic island ecosystems.	166,167

**Table S3.** Summary of key governance processes associated with each ocean claim.

Claim	Governance
Seafood	<p>The United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994) constitutes the primary governance framework for marine capture fisheries, defining Exclusive Economic Zones (EEZs) within which the coastal state has ‘sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living’ (Article 56). In the case of shared stocks (i.e. extending across the EEZ of one or more coastal nation), states are called upon to ‘seek, either directly or through appropriate sub-regional or regional organizations, to agree upon the measures necessary to coordinate and ensure the conservation and development of such stocks’. The UN Fish Stocks Agreement (signed 1995, entered into force 2001) applies in the case of straddling stocks (i.e. extending across one or more EEZs and into areas beyond national jurisdiction) and highly migratory stocks (i.e. defined as such in Annex 1 of UNCLOS) to devolve management responsibilities to a network of regional fisheries management organizations (RFMOs). Under the aegis of the Food and Agriculture Organization of the United Nations (FAO), a further legally binding instrument of relevance to fishing activities is the FAO Compliance Agreement (signed 1993, entered into force 2003), which strengthens the role and responsibility of flag states with regard to vessels engaged in fishing on the high seas. Finally, the Agreement on Port State Measures (PSMA) (signed 2009, entered into force 2016) includes provisions to enhance portside controls aimed at eliminating the landing of fish sourced from illegal, unreported or unregulated (IUU) activities. A suite of voluntary international standards and guidelines of relevance to aquaculture and capture fisheries have also been developed by FAO, such as the Code of Conduct for Responsible Fisheries (1995), International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (1999), and the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (2015). Beyond UNCLOS and the FAO, other relevant international organizations include the Convention on Biological Diversity (commitment by signatories to conservation and sustainable use of biodiversity), the International Labour Organization (commitment to fair and safe employment conditions), and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (commitment to ensure trade of wild animals without threatening their survival). A diverse landscape of voluntary environmental programs, including certification schemes, private-public partnerships, and industry-led initiatives have also emerged over the past decades. Notable examples include the Marine Stewardship Council (1996) and Aquaculture Stewardship Council (2010), as well as the Global Sustainable Seafood Initiative (GSSI), which aims to benchmark seafood certification schemes against FAO guidelines. Voluntary industry-led initiatives include for instance the Coalition of Legal Toothfish Operators (2003), the Global Salmon Initiative (2013), and the Seafood Business for Ocean Stewardship (2016).</p>
Feeds and nutraceuticals	<p>The production of marine ingredients for aquaculture and livestock feeds as well as the production of nutraceuticals rest on the removal of biomass from marine ecosystems or the use of waste products generated by the seafood industry. Particularly relevant governance mechanisms therefore include commitments to conservation and sustainable use of biological diversity enshrined in the Convention on Biological Diversity (signed 1992, entered into force 1993), as well as the rights and responsibilities of coastal states to conserve and manage living resources within their EEZ, as described in the United Nations Convention on the Law of the Sea (signed 1982, entered into force 1994). Examples of related voluntary industry-led initiatives include the Marine Ingredients Organisation (2001), the Aquaculture Stewardship Council (2010) and the Global Salmon Initiative (2013).</p>

Hydrocarbons	<p>Offshore oil and gas extraction takes place on the continental shelf, where, according to Article 56 of the United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994), coastal states have 'sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living'. The seabed beyond national jurisdiction, described as 'the Area' under Part XI of UNCLOS, falls under the jurisdiction of the International Seabed Authority (ISA), which is in the process of developing exploitation regulations. If oil or gas extraction begins in the Area in the future, it will be in accordance with the ISA regulatory framework. While the entirety of hydrocarbons extraction currently takes place within national jurisdictions, a number of international voluntary initiatives exist to promote best practices and sharing of experience. The International Regulators Forum (1993) convenes biannual or triannual meetings between health and safety regulators dealing with the offshore oil and gas industry. Additional voluntary programs that encompass both onshore and offshore hydrocarbon activities include the global oil and gas industry association for advancing environmental and social performance (IPIECA), as well as the International Association of Oil &amp; Gas Producers (IOGP).</p>
Minerals	<p>Article 56 of the United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994), grants coastal states within their exclusive economic zones, sovereign rights over the exploration and exploitation of natural resources, both living and non-living. In the seabed beyond national jurisdiction (the Area), Part XI of UNCLOS places responsibility for managing mineral resources with the International Seabed Authority (ISA, founded 1994). The resources in the Area are considered the 'common heritage of mankind' (Article 136) and subject to equitable sharing of financial benefits related to extraction activities. Regulations on commercial seabed mining are currently under negotiation within the ISA (the Mining Code) and are expected to be approved within the next two years. Mining contractors are required to identify areas (i.e. preservation reference zones) that are ecologically comparable to areas where mining is intended. In addition, the ISA is establishing Regional Environmental Management Plans (REMPs) including the designation of Areas of Particular Environmental Interest (APEIs) where mining activities will not be allowed. One such REMP has been established for the Clarion-Clipperton Fracture Zone in the Pacific Ocean and comprises nine APEIs spanning 1.4 million km<sup>2</sup> of the seabed. Commercial mining activities have not yet begun in the Area, but voluntary industry initiatives for the mining of metal and minerals exist, including the International Council on Mining and Metals (established in 2011), which involves 27 mining companies and 34 associations committed to improving environmental and social performance. The Extractive Industries Transparency Initiative was established in 2003 and provides a global standard for good governance in extractive industries, with membership by 52 countries.</p>
Desalinated water	<p>While no international obligation exists with regard to desalination activities, states are nevertheless committed under Part XII of the United Nations Convention on the Law of the Sea (signed 1982, entered into force 1994) 'to protect and preserve the marine environment' (Article 192) and 'to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other States and their environment' (Article 194). The International Desalination Association (established 1973) is the world's leading resource for information and professional development for the global desalination industry, including 4,000 members across 60 countries, but membership does not involve any commitments.</p>
Ornamental resources	<p>Article 56 of the United Nations Convention on the Law of the Sea (signed 1982, entered into force 1994) provides coastal states with 'sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living'. Ornamental resources are therefore within the purview of national governments with the exception of species that have been designated for special protection under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (signed 1973, entered into force 1975). Approximately</p>

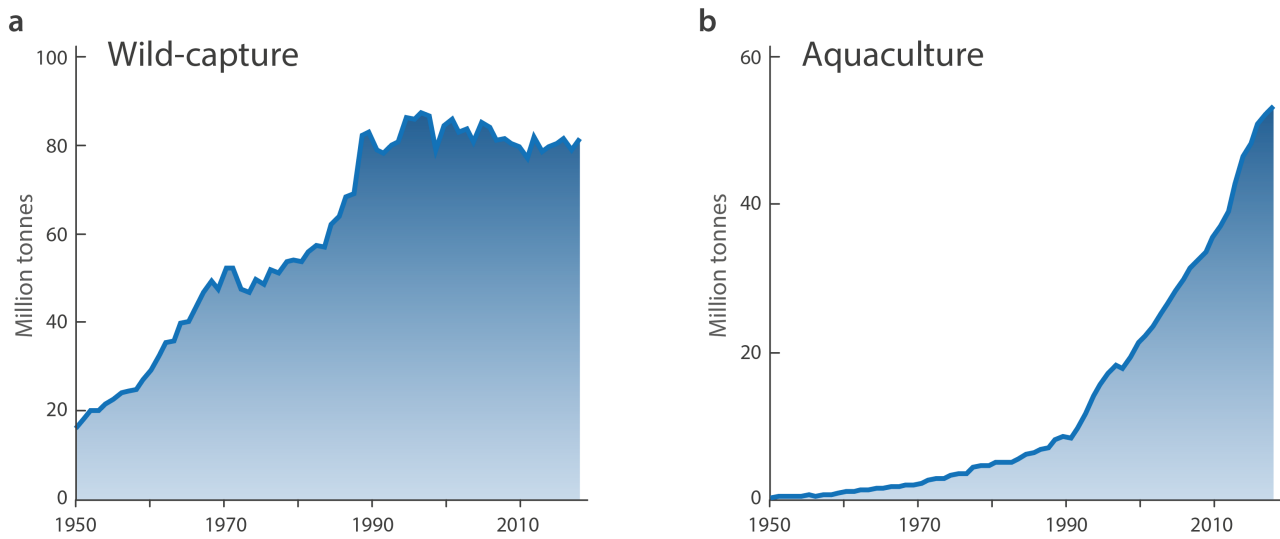
	<p>35,000 species of plants and animals are afforded some degrees of protection under CITES, which is binding for the 183 parties who have agreed to adhere to the convention. Its legal reach does not extend to non-parties.</p>
Genetic resources and derived products	<p>The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (signed 2010, entered into force 2014) is the key reference point for governing access to genetic resources and subsequent sharing of benefits from their use. Provider countries (where genetic resources are located) and user countries (those seeking access to these genetic resources) must arrive at mutually agreed terms (Article 18) based on prior informed consent (Article 6). Negotiations are currently advancing under the auspices of the Conference of the Parties to the Convention on Biological Diversity with regard to the status of digital sequence information, also referred to as genetic sequence data, that results from the sequencing of genetic resources. In areas beyond national jurisdiction (ABNJ), a liberal access regime persists in which no limitations are placed on the collection of marine genetic resources or their subsequent use. This governance gap is one of the pillars of the ongoing negotiations for a new implementing agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of ABNJ, in line with UN General Assembly Resolution 72/249.</p>
Scientific information	<p>Under the United Nations Convention on the Law of the Sea (signed 1982, entered into force 1994), all states are granted the right to conduct marine scientific research (Part XIII), including in the Area (Article 256) and the High Seas (Article 257). Multiple voluntary best practices exist for the handling of scientific information, including the FAIR Guiding Principles for scientific data management and stewardship, according to which data should meet standards of findability, accessibility, interoperability and reusability. FAIR data principles have been endorsed by national governments and science agencies as well as the G20 at the 2016 Summit in Hangzhou. The deposition of genetic sequence data within public databases that are part of the International Nucleotide Sequence Database Collaboration (INSDC), notably those maintained by the National Center for Biotechnology Information, the DNA Data Bank of Japan, and the European Molecular Biology Laboratory, is required by some national science agencies and most journals dealing with biotechnology and genomic studies. The Ocean Biogeographic Information System, the Global Biodiversity Information Facility, the World Register of Marine Species and the World Ocean Database are just a few of the aggregation sites compiling scientific information relating to the biogeochemistry of the ocean and its biological and genetic diversity.</p>
Shipping	<p>Flag states are designated as the primary mechanism for ensuring compliance with international conventions regulating the shipping industry, as described in Articles 93-94 (for the High Seas) and Article 217 (across all jurisdictions) of the United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994). The International Maritime Organization (IMO; 1948) predates UNCLOS and was established under the auspices of the United Nations to develop and continuously update the regulatory framework associated with shipping, similar to the International Labour Organization (ILO; 1919) which promotes decent work and social justice. Both the IMO and ILO have developed multiple conventions of particular relevance to the shipping industry, which in accordance with UNCLOS are to be codified into the national legal framework of the respective flag states. For instance, the Convention on the Prevention of Pollution from Ships (MARPOL Convention; 1978) aims at minimising pollution to the ocean from maritime traffic. The MARPOL Convention has been repeatedly expanded, perhaps most notably in 1988 with regulations on the dumping of garbage from ships, resulting in a complete ban on dumping plastic into the ocean. The Safety of Life at Sea (SOLAS; adopted 1974, entered into force 1980) sets minimum standards for safety-related to maritime transport, including the construction of ships and their operations. The International Convention for the Control and Management of Ships' Ballast Water</p>

	<p>and Sediments (BWMC; adopted 2004, entered into force 2017) seeks to counteract the spread of invasive species in ballast water by calling for mid-ocean exchange of ballast water. The Maritime Labour Convention (MLC; adopted 2006, entered into force 2013) sets forth minimum standards with regards to seafarers' rights of decent work conditions. Other relevant conventions relate to transport and storage of specific cargoes (e.g. International Maritime Solid Bulk Cargoes Code, Hazardous and Noxious Substances by Sea Convention), some focus on liability in cases of pollution or maritime accidents (e.g. International Convention on Civil Liability for Bunker Oil Pollution Damage, International Convention on Civil Liability for Oil Pollution Damage, Nairobi Convention on the Removal of Wrecks), while the International Regulations for Preventing Collisions at Sea aim at reducing the risk of ship collisions. In addition to this landscape of legal instruments, several voluntary industry initiatives have emerged with ambitions extending beyond legal minimum standards. These include, for instance, the Sustainable Shipping Initiative (2012), whose members have committed to increasing transparency and mainstreaming sustainability practices into their operations.</p>
Pipelines and cables	<p>Rights and responsibilities associated with the laying of submarine cables and pipelines are addressed together under the United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994). Coastal states are entitled to lay submarine cables and pipelines on the continental shelf (i.e. within their jurisdiction) and must seek the consent of other coastal states if the submarine cable or pipeline enters foreign jurisdiction (Article 79). In areas beyond national jurisdiction, all states are 'entitled to lay submarine cables and pipelines on the bed of the high seas beyond the continental shelf' (Article 112). Liability issues related to the damage to submarine cables and pipelines are outlined in UNCLOS as well, including the responsibility of states to have appropriate regulations in place to address cases of willful or accidental damage (Articles 113-114), and the liability of cable and pipeline owners if other operators 'can prove that they have sacrificed an anchor, a net or any other fishing gear, in order to avoid injuring a submarine cable or pipeline' (Article 115). States are likewise obligated under Part XII of UNCLOS 'to protect and preserve the marine environment' (Article 192) and 'to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other States and their environment' (Article 194). The International Cable Protection Committee (ICPC), established in 1958, includes over 175 members from more than 60 countries. While a non-binding body, the ICPC members seek, among other things, to 'produce and maintain industry recommendations that define the minimum standards for cable route planning, installation, operation, maintenance and protection', and serve as a clearinghouse for the latest technical and environmental information related to the submarine cable industry.</p>
Tourism and recreation	<p>Marine and coastal tourism encompasses all ocean-related tourism and leisure activities that take place in coastal areas and the offshore waters. Often occurring at the land-sea interface, it involves governance of multiple sectoral organisations and has traditionally focused on marine spatial planning and the implementation of regulations, permits and licences that have a legal basis and require enforcement by national authorities. Yet international agencies also play an important role in the planning and management of tourism. The World Tourism Organization (UNWTO, founded in 1975) is the United Nation specialised agency responsible for the promotion of responsible, sustainable and universally accessible tourism. Neither 'tourism' nor 'recreation' appears specifically in the United Nations Convention on the Law of the Sea (signed 1982, entered into force 1994), but states are nevertheless committed under Part XII 'to protect and preserve the marine environment' (Article 192) and 'to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other States and their environment' (Article 194). Tourism is also enshrined in the Sustainable Development Goal 14 - Conserve and sustainably use the oceans, seas and marine resources for sustainable development, under target 14.7. The International Whaling Commission (established 1946), instituted two strategic plans on whale</p>

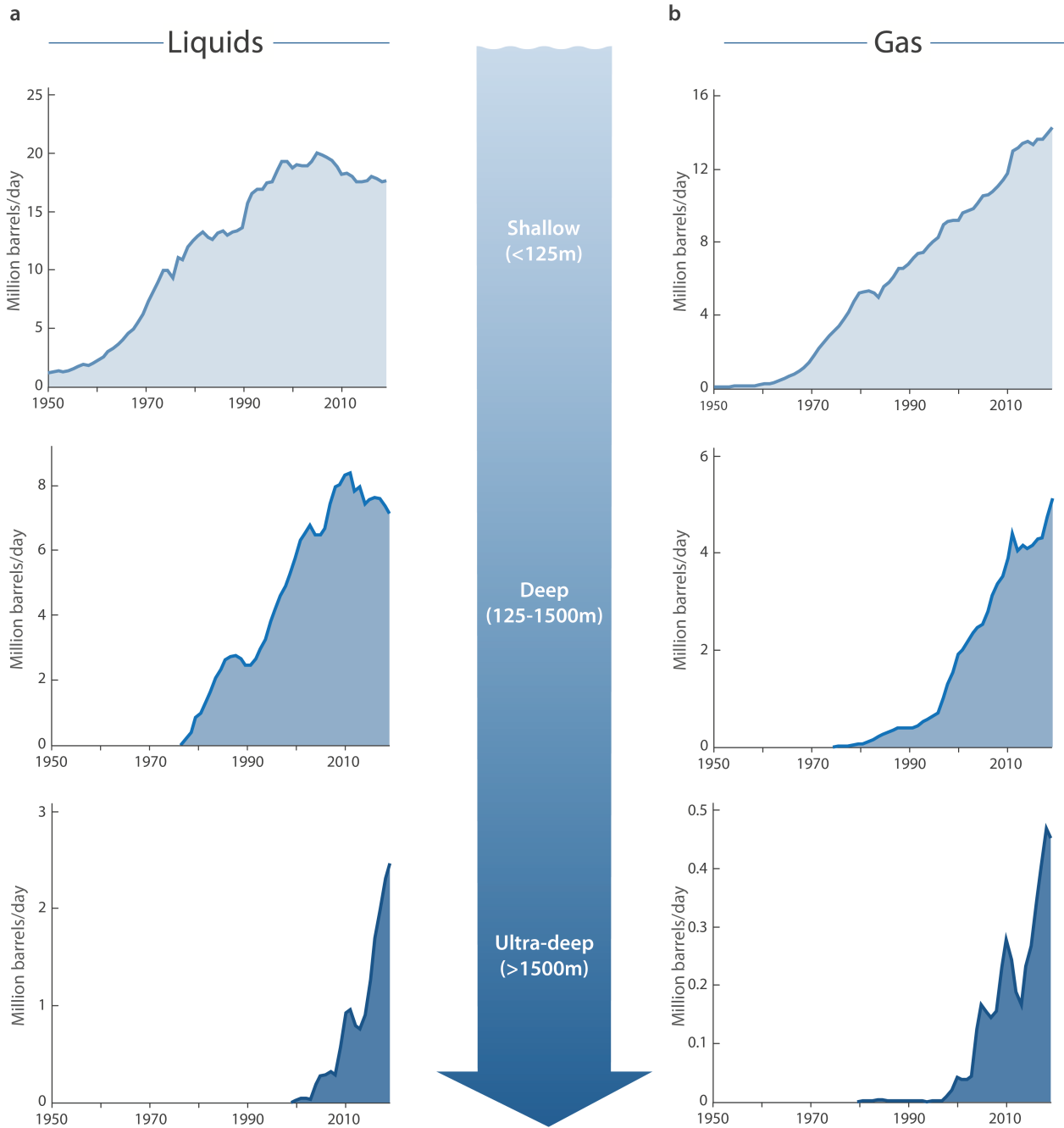
	<p>watching (2011-2016 and 2018-2024) to provide a framework for research and management by national authorities in support of responsible and sustainable practices. A special case of ocean tourism is presented by cruise ships, which governance falls under flag states and the regulatory bodies in charge of shipping, including the International Maritime Organization (IMO; 1948) and the Convention on the Prevention of Pollution from Ships (MARPOL Convention; 1978). Members of the Cruise Lines International Association (CLIA, founded 1975), the world's largest cruise industry association, have committed to reduce the rate of carbon emissions across the industry fleet by 40% by 2030.</p>
Land reclamation	<p>Under the United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994), coastal states are granted 'the exclusive right to construct and to authorize and regulate the construction, operation and use of artificial islands' within their exclusive economic zone and continental shelf (Articles 60 and 80). The construction of artificial islands does not result in designation of additional territorial seas and therefore does not affect the delimitation of the exclusive economic zone or continental shelf (Article 60, Paragraph 8). The construction of artificial islands is likewise permitted on the High Seas (Article 87) although subject to the provisions under Part VI of UNCLOS.</p>
Renewable energies	<p>In accordance with Article 56 of the United Nations Convention on the Law of the Sea (signed 1982, entered into force 1994), each 'coastal state has sovereign rights [...] with regard to [...] activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds'. Although offshore and floating wind farms have been developed, to date none are located in areas beyond national jurisdiction and no international regulatory or governance specifically address this possibility. State-led international institutions such as the International Energy Agency (founded 1974) and the International Renewable Energy Agency (founded 2009) encompass a broad range of energy issues, with a strong focus on the transfer of technology and capacity development, but without a mandate for regulatory control. Noting the damage to migratory bird populations from wind turbines, the Convention on the Conservation of Migratory Species has called upon its parties 'to identify areas where migratory species are vulnerable to wind turbines and where wind turbines should be evaluated to protect migratory species [...] and to [...] take full account of the precautionary principle in the development of wind turbine plants' (Resolution 7.5, adopted in 2002). Non-binding measures have been proposed by the East Asian-Australasian Flyway Partnership, and within the National Biodiversity and Action Plans submitted by parties to the Convention on Biological Diversity. Voluntary industry associations and initiatives have also emerged to promote best practices within the renewable-energy industry, including WindEurope (founded 1982) and Ocean Energy Europe (founded 2000).</p>
Geoengineering	<p>International governance related to geoengineering is considered to comprise a regulatory gap in need of urgent attention. The intentional release of iron into the ocean, referred to as iron fertilization, has been addressed under UNCLOS to the extent that the activity is considered to constitute 'dumping' (UNCLOS, Articles 1, 210, 216). Since 2007, it has been more specifically included in the scope of the London Convention (adopted 1972, entered into force 1975) and the London Protocol (adopted 1996, entered into force 2006) which regulate the deliberate disposal at sea of wastes and other matter. Amendments adopted in 2013 via resolution LP.4(8) added a new article 6bis stating that 'Contracting Parties shall not allow the placement of matter into the sea from vessels, aircraft, platforms or other man-made structures at sea for marine geoengineering activities listed in Annex 4, unless the listing provides that the activity or the sub-category of an activity may be authorized under a permit'. An ocean fertilization activity may only be considered for a permit if it is assessed as constituting legitimate scientific research. Proposed scientific research is considered under the 2010 Assessment Framework for Scientific Research involving Ocean Fertilization (resolution LC-LP.2).</p>

Waste disposal	<p>The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (adopted 1972, entered into force 1975), also known as the London Convention, was one of the first international agreement for the protection of the marine environment. It requires contracting parties to issue a permit for the deliberate disposal at sea of wastes and other matters from vessels, aircraft, platforms and other man-made structure, and generally prohibits the dumping of hazardous materials. The London Protocol (adopted 1996, entered into force 2006) improved the London Convention by requiring the parties to prohibit the dumping of any wastes or other matter with the exception of those listed in Annex 1 to the Protocol (e.g., dredged material, sewage sludge, fish waste, inorganic geological material, organic material of natural origin, man-made structure). The London Protocol provides a more restrictive international standard that should eventually supersede the London Convention. Waste disposal is characterised as ‘dumping’ under the United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994) in the case of ‘deliberate disposal of wastes [...] at sea’ (Article 1). UNCLOS calls upon states to adopt laws and regulations that are aimed at preventing, reducing and controlling pollution due to dumping (Article 210) and defines the corresponding enforcement capacities of both coastal states and flag states (Article 216). In the case of maritime transport, more extensive binding regulations exist under the Convention on the Prevention of Pollution from Ships (MARPOL Convention; 1978), which aims at minimising pollution to the ocean from maritime traffic. Over the years, the MARPOL Convention has been continuously expanded, including in 1988 with regulations on the dumping of garbage from ships, resulting in a complete ban on dumping plastic into the ocean. With regard to the seafood industry, several UN General Assembly Resolutions relate to minimising abandoned, lost or discarded fishing gear (ALDFG), primarily calling upon states to gather more data about the issue and how to address it (e.g. A/RES/60/30-31, A/RES/61/222). The FAO Code of Conduct for Responsible Fisheries (1995) calls for the reduction of ALDFG (Article 8), while the Voluntary Guidelines on the Marking of Gear (2019) provides operational guidance that could help to limit the incidence of ALDFG.</p>
Conservation	<p>Conservation is a cross-cutting issue as reflected in the regulation and governance of multiple sectoral organisations. The United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994) grants coastal states within their exclusive economic zones, ‘sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living’ (Article 56) and requires them to ‘ensure through proper conservation and management measures that the maintenance of the living resources in the exclusive economic zone is not endangered by over-exploitation’ (Article 61). In the High Seas, states ‘have the duty to take, or to cooperate with other States in taking, such measures for their respective nationals as may be necessary for the conservation of the living resources of the high seas’ (Article 117). Under the Convention on Biological Diversity (CBD) (signed 1992, entered into force 1993), parties have also agreed that ‘States are responsible for conserving their biological diversity’ and to develop national biodiversity strategies and action plans for the conservation and sustainable use of biodiversity. Parties have likewise committed to the CBD Strategic Plan and its 20 Aichi Biodiversity Targets, which include commitments to designate 10% of marine and coastal areas for special protection by 2020 (also target 14.5 under Sustainable Development Goal 14). Similarly, parties to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (1975) have agreed to grant specific protections to approximately 35,000 species of plants and animals designated under CITES. Among the many conservation measures existing within sectoral organisations are a range of area-based management tools. Regional fisheries management organisations (RFMOs) are required under the UN Fish Stocks Agreement (signed 1995, entered into force 2001), to ensure the long-term conservation and sustainable use of straddling fish stocks and highly migratory fish stocks (Article 2) in line with a precautionary approach (Article 6) and are empowered to implement conservation measures (Article 8), including the designation of Vulnerable Marine Ecosystems (VMEs) (provided for in UN General Assembly Resolution 61/105).</p>

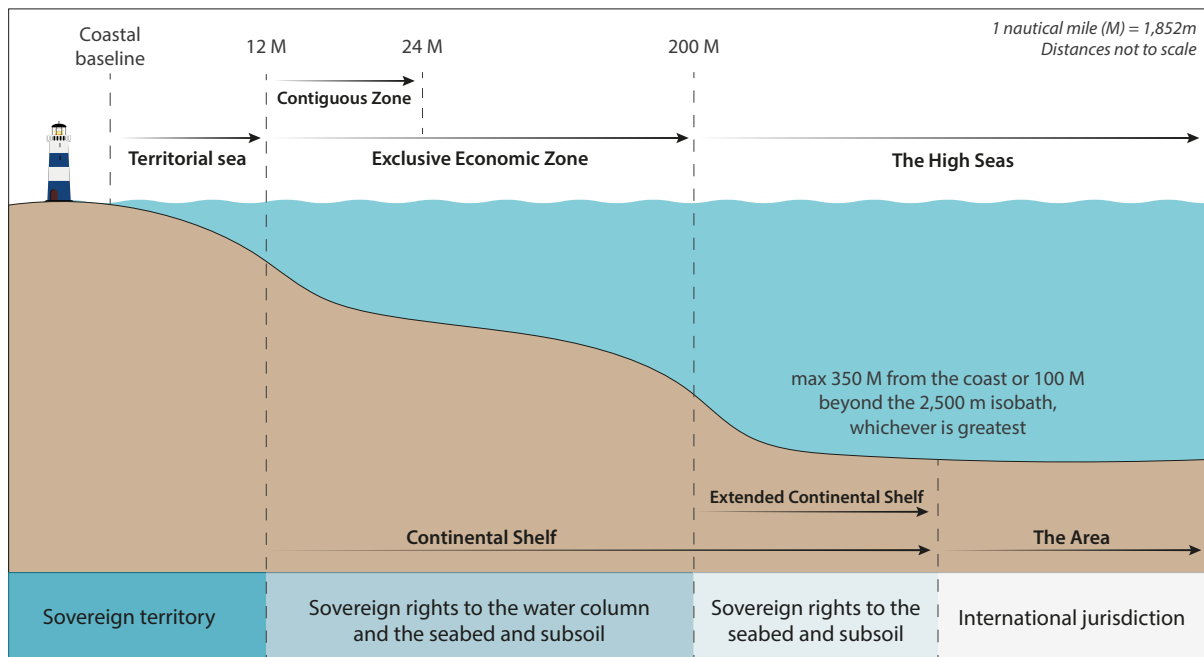
	<p>Similarly, the International Maritime Organization (IMO) (1948) passed resolution A.982(24) in 2005, allowing for the identification and designation of Particularly Sensitive Sea Areas (PSSAs), each of which ‘needs special protection through action by IMO because of its significance for recognized ecological, socio-economic, or scientific attributes where such attributes may be vulnerable to damage by international shipping activities’ (Res. 982, Annex, Paragraph 1.2). The International Seabed Authority (ISA, founded 1994) has begun to establish Regional Environmental Management Plans (REMPs) including the designation of Areas of Particular Environmental Interest (APEIs) where mining activities will not be allowed. Under the auspices of the CBD, it was also agreed to begin a process to identify Ecologically or Biologically Significant Areas (EBSAs) in line with specific scientific criteria (CBD COP9, Decision 20, Annex 1). Although the identification of EBSAs does not automatically entail any special conservation measures, states have in some instances used these to designate marine protected areas (MPAs), a common conservation measure within national jurisdictions. In areas beyond national jurisdiction, no overarching international binding mechanism currently exists for the designation of MPAs. This is one of the pillars of the ongoing negotiations on a new implementing agreement under UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction in line with UN General Assembly Resolution 72/249.</p>
Territorial boundaries	<p>The different territorial zones and the corresponding rights and responsibilities associated with each are detailed in the United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994). These include the territorial sea and contiguous zone (Part II), the Exclusive Economic Zone (Part V), the continental shelf (Part VI), the High Seas (Part VII), and the Area (Part XI). Recognising that in some cases the continental shelf extends more than 200 nautical miles beyond the limits of the territorial sea, Annex II to UNCLOS includes a statement of understanding on the determination of the limits of the continental margin. Article 76 of UNCLOS provides states with the right to make extended continental shelf claims that extend beyond the 200 nautical miles limit for consideration by the Commission on the Limits of the Continental Shelf. Part XV of UNCLOS details the provisions for dispute settlement, including with regard to competing territorial claims.</p>
Military activities	<p>Military uses of ocean space involve both movement rights (i.e. mobility of seaborne forces) and operational rights (e.g. military exercises, weapons testing, intelligence collection). The United Nations Convention on the Law of the Sea (UNCLOS) (signed 1982, entered into force 1994) codified only movement rights, leaving military activities essentially unregulated and subject to interpretation. Article 87 of UNCLOS provides that the high seas are open to all States, whether coastal or land-locked, for the freedoms of navigation and overflight – for peaceful purposes (Article 88). Article 58 recognises that in the exclusive economic zone (EEZ), all States enjoy ‘the freedoms referred to in article 87 of navigation and overflight [...] and other internationally lawful uses of the sea related to these freedoms, such as those associated with the operation of ships, aircraft and submarine cables and pipelines’. Under the doctrine of freedom of the seas, many nations interpret these articles by considering that military operations are a form of ship operations and are therefore allowed in both high seas and the EEZ. Others advocate what has been referred to as ‘controlled access’, whereby foreign military operations should be prohibited within EEZs given ‘States shall have due regard to the rights and duties of the coastal state’ (Article 58). While military vessels must generally comply with the same rules as merchant ships, it remains unclear whether unmanned military devices are considered ships under UNCLOS. Nuclear testing in all environments, including underwater, is banned under the Comprehensive Nuclear-Test-Ban Treaty (adopted 1996 but not yet entered into force). The San Remo Manual on International Law Applicable to Armed Conflicts at Sea (adopted 1994) is a legally recognised (but not binding on states) codification of laws governing the conduct of hostilities at sea.</p>



**Figure S1. Global seafood production.** Temporal trends in **(a)** marine wild-capture fisheries and **(b)** marine aquaculture global production from 1950 to 2017. Wild-capture volumes increased rapidly during the post-war period, peaking in 1996, and declining since then despite an escalation in global fishing effort and improved technology allowing to fish deeper and farther. The farming of aquatic organisms dramatically increased over the last few decades and still is the world's fastest-growing food production sector.



**Figure S2. Global offshore liquids and gas production across depth.** Temporal trends in global offshore production volumes of (a) liquids and (b) gas from 1950 to 2018, across water depth categories: shallow (<125m), deepwater (125-1500m) and ultra-deepwater (>1500m). Liquids include both crude oil and natural gas liquids. Production is sequentially moving towards greater depths as new technologies emerge and shallow-water fields begin to stagnate or decline.



**Figure S3. Maritime zones according to the United Nations Convention on the Law of the Sea (UNCLOS).** Sovereignty in the territorial sea extends to the air space, water column, seabed and subsoil. The contiguous zone is a limited enforcement zone where a state can exert control for preventing or punishing infringement of its customs, fiscal, immigration or sanitary laws and regulations within its territory or territorial sea. The exclusive economic zone grants sovereign rights for exploring, exploiting, conserving and managing living and non-living resources of the water column, seabed and subsoil. Over the continental shelf, a state has sovereign rights for exploring and exploiting non-living resources of the seabed and subsoil, plus sedentary species. Claims of extended continental shelves (ECS) are received by the United Nation Commission on the Limits of Continental Shelf and payments for the exploitation of non-living resources in the ECS are made through the International Seabed Authority (ISA). Areas beyond national jurisdiction are designated as The High Seas (water column) and the Area (seabed and subsoil). Non-living resources in the Area are administered by the ISA.

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