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Assessment of the geographical potential for co-use of marine space, based on operational boundaries for Blue Growth sectors

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ABSTRACT

The worlds' oceans and seas have tremendous potential to contribute to the provision of food, feed, energy and natural resources. The emerging concepts of "Blue Growth" and "Blue Economy" have put the development of new marine industries on the political agenda. As marine industries expand, spatial interconnections and industry boundaries are being drawn and the potential for the combined use of marine space is being explored. The aim of this paper is to provide a single source document that summarizes the probable boundaries of marine growth industries, namely aquaculture; offshore wind energy with fixed foundations; floating offshore wind energy; tidal and wave energy; marine biotechnology, seabed mining; and tourism and recreation, based on depth and distance from the shore. This is an important first step in developing a single source document for marine industry boundaries that will help marine spatial planners and researchers develop innovative industry combinations to foster growth in the marine sector. This paper explores marine industry overlaps in four basins: European Atlantic, Baltic/North Sea, Mediterranean/Black Sea and the Caribbean/ Gulf of Mexico. By describing the geographical characteristics of different sea basins, this paper helps to focus marine governance strategies for stimulating combinations of marine industries towards the most promising areas. The methodology developed in this paper was also used to generate 72 country-specific maps and corresponding tables to support marine spatial planning processes at a national level.

1. Introduction

The world's oceans and seas have tremendous potential to contribute to the global economy through the supply of food, energy and natural resources. The emerging concepts of "Blue Growth" and "Blue Economy" are used across the world to capture this potential and bring these concepts to the forefront of the political agenda [21,77]. In the international development sphere, the FAO Blue Growth Initiative seeks to reconcile economic growth with improved livelihoods and social equity through sustainable use of aquatic natural resources in capture fisheries and aquaculture, ecosystem services, trade, livelihoods and food systems [23]. The European Commission coined the term "Blue Growth" to emphasize the economic potential of the maritime sectors aquaculture, offshore energy, marine biotechnology, seabed mining and tourism [14,18].

As both the variety and absolute number of marine commercial activities increase, competition for space in countries' exclusive economic zones (EEZs) increases. This trend is amplified by the establishment of marine protected areas (MPAs), which have a goal of protecting biodiversity and helping to meet sustainable development targets [51,59].

One of the major purposes of marine spatial planning is to ensure that all activities that take place in the marine space can function together in a sustainable way [61]. Competition for space has triggered research into the potential for combining different industries and technologies in ocean spaces. Combining compatible industries allows for more efficient use of space, enables various sectors to cooperate in the same area and develop synergies, both of which can lead to cost-savings (see for example [39,52,79,70]).

Research efforts like these are driven by an interest in technical and/or economic feasibility. Such efforts broaden the body of knowledge on the multiple use of marine space (multi-use), but are of limited relevance in marine spatial planning because they do not provide specific insight into the geographic potential of multi-use combinations according to sea basin. Furthermore, there are no scientific publications that identify the physical boundaries of the various marine industries

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and analyze different marine basins with the purpose of identifying potential industry combinations and the amount of ocean space suitable for these combinations.

The main research question addressed in this paper is: *What are operational boundaries for Blue Growth industries and the resultant geographic potential for the multi-use of space*? Answering this question requires further investigation into the boundaries of the relevant marine industries, analysis of the geographical conditions and a review of the potential for multi-use. The following sub-questions therefore need to be addressed:

1. What are the operational boundaries required for the Blue Growth industries?
2. What areas in the different sea basins are available and suitable for these industries, when considering all areas and when taking into account MPAs?
3. What are the consequences for the development of multi-use combinations and marine spatial planning in the regions concerned?
4. What are the main non-operational barriers to the multi-use of sea space?
5. How can the methodology developed in this paper support marine spatial planning processes?

This paper provides a single source document that summarizes the boundaries of seven different Blue Growth sectors: aquaculture; offshore wind energy with fixed foundations; floating offshore wind energy; tidal and wave energy; marine biotechnology, seabed mining; and tourism and recreation, by depth and distance from the shore. Depth and distance to shore are important parameters that determine the feasibility of new offshore activities (see e.g. [8]).

This is an important first step for identifying potential combinations for the marine industries and providing a method for future analysis of other operational boundaries. Collating this information will help marine spatial planners and researchers to accommodate multi-use in marine spatial planning and assess the impact for marine basin strategies.

1.1. Scope of this study

The Horizon 2020 Marine Investment for the Blue Economy (MARIBE) project was one of a number of European Union research projects that have focused on the multiple use of marine space. This paper focuses on the four marine basins studied in the MARIBE project: European Atlantic, the North Sea/Baltic, Mediterranean/Black Sea and the Caribbean/Gulf of Mexico. The methods used are applicable to other marine basins and results of the MARIBE project are available at https://maribe.eu/. The results presented are not a duplication of the content of project reports.

This paper focuses on the Blue Growth sectors as identified by the EU [16], because these marine sectors will occupy considerable amounts of space [37]. More traditional marine sectors such as shipping and offshore oil and gas are not included in the analysis. This is because, although shipping lanes are spatially extensive, their operational boundaries are of limited relevance in planning, and fixed stationary structures (oil and gas) are excluded because they take up very little space. Other sectors, including fisheries, transport and sand dredging are mobile and often not limited by operational boundaries.

For the purposes of this analysis, operational boundaries are limited to water depth and distance to shore. Other operational boundaries are also important, e.g. distance from conservation areas, distance from marine infrastructure (e.g. oil platforms) and distance from shipping lanes. However, the methodology described herein can accommodate other marine sectors and other types of boundaries, but these are beyond the scope of this paper.

1.2. Juridical boundaries

This paper focusses on those parts of the sea under the authority of nation states. Territorial seas and the contiguous zone are included in the EEZ. Coastal states can essentially exercise the same rights of sovereignty over their seas as they do over land but there are some international obligations, including the right to passage by ships. Coastal states are entitled to legislate in order to protect facilities and installations within the territorial seas, but must give due publicity to their laws and regulations ([68], Art.21 [4]).

A state's territorial sea extends up to 12 NM (22 km) from its baseline. The baseline is the low water line along the coast that is officially recognized by the coastal state. Straight baselines can alternatively be defined as connecting fringing islands along a coast, across the mouths of rivers, or with certain restrictions across the mouths of bays.

The contiguous zone is a band of water extending from the outer edge of the territorial sea up to 24 NM (44 km) from the baseline. A state's EEZ is an area that extends seawards to a distance of no more than 200 NM (370.4 km) from its coastal baseline, thus it includes the contiguous zone. Coastal states have control of all economic resources within their EEZ. The international waters (or high seas) are oceans, seas and waters beyond national jurisdiction, termed ABNJ (Fig. 1).

Under the United Nations Convention on the Law of the Sea (UNCLOS), coastal states may seek ownership of the extended continental shelf beyond 200 NM, if the requirements in UNCLOS article 76 are met. This procedure is under the control of the Commission on the Limits of the Continental Shelf. Successful application grants Coastal States the economic rights to exploit the resources on and in the seabed, but not the waters above the seabed. For this reason, the extended continental shelf areas are excluded from the analysis below.

2. Method

The identification of the operational boundaries was done by review of literature and expert consultation as part of the MARIBE project. Within MARIBE, different combinations of marine industries were detailed in cooperation with industry experts, businesses and academic experts. Additionally, the resulting combinations were presented and discussed at a workshop (organized in Brussels, Belgium in June 2016) with a 13-member expert panel represented by industries including banking, financial services, multinational professional services, engineering procurement and construction services, naval architecture, research institutes, ocean energy and aquaculture, among others.

For the subsequent spatial analyses, selected marine basins were delineated into maritime boundaries based on Version 9 of the World EEZ data set [11]. Within each EEZ, buffers were created for regions extending out to 5, 12, 16, 24 and 200 NM from land areas extracted from the Global Administrative Unit Layers (GAUL) data set (FAO, 2015b). Distance bands at 12, 24 and 200 NM are commonly used EEZ designations, and additional bands at 5 and 16 NM were included to improve the spatial precision of the analyses. In rare cases, marine regions were classified as being within an EEZ but were $>$ 200 NM from shore. Therefore, a separate classification was created for these areas. Marine basins were delineated into depth ranges using bathymetric data from the General Bathymetric Chart of the Oceans (GEBCO) [72,73]. Surface areas were classified into depth range bands of > -10 m, -10 m to -50 m, -50 m to -100 m, -100 m to -150 m, -150 m to -200 m, and < -200 m. In the following figures and tables, the phrase “less than 200 m” and the symbol “< -200” refer to water deeper than 200 m. All spatial analyses were performed in ArcMap 10.4.

Even though MPAs do not exclude all users – for example, tourism activities are allowed in most MPAs – for ecological or conservation reasons, access to MPAs is usually restricted or forbidden to certain types of development. These waters were classified as *protected* if they were defined as such in the World Database of Protected Areas (WDPA) [32].

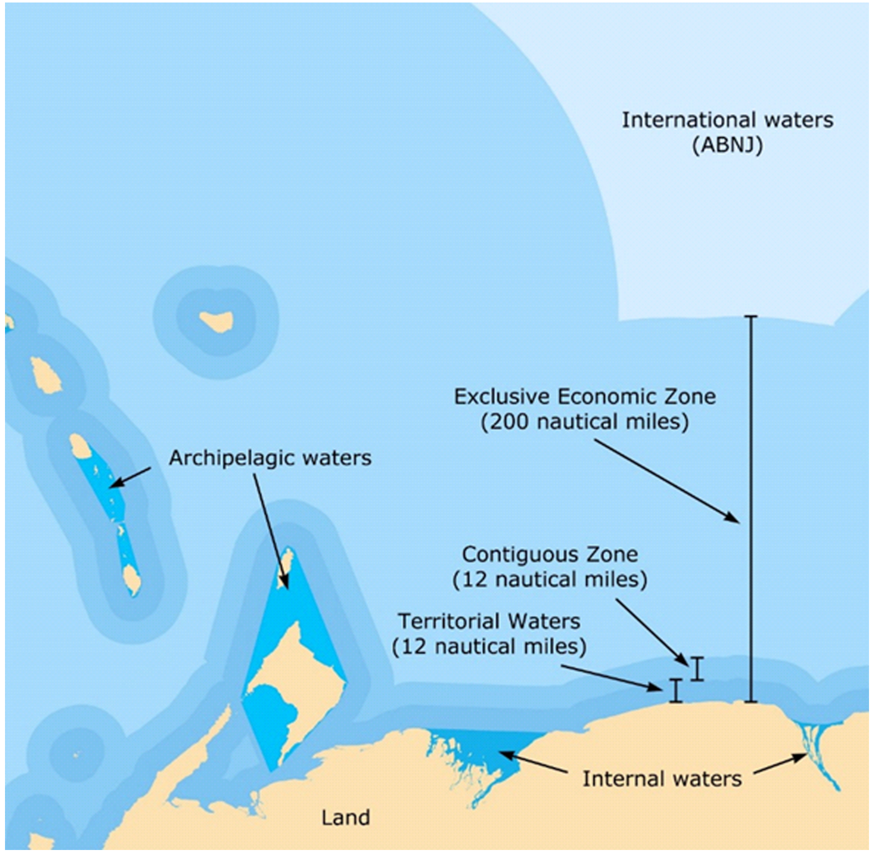


Fig. 1. Generalized sea areas and jurisdiction in international rights (source: modified from [68]).

Jurisdictional boundaries, distance-to-shore buffers, depth range bands, and protected areas were intersected to produce a dataset that identified all areas within the EEZ of each marine basin. Areas of each polygon were calculated using spherical trigonometric methods on latitude/longitude coordinates as described in Jenness [35]. The respective areas were then summed to produce tables describing the cumulative area in each unique combination of maritime boundary, distance to shore, depth range and protected status.

The coastline length data were derived from the GAUL Administrative Unit polygons (FAO, [21]). GAUL is a high-resolution global boundary dataset digitized at approximately one vertex every 300 m. This data set of marine coastlines was derived by (1) creating an "Ocean" data set by clipping out the GAUL polygons from a general background polygon covering the entire earth; (2) deleting all small polygons from the Ocean data set which represented lakes or internal holes in the GAUL data set; and (3) creating a coastline data set by intersecting the GAUL polygons with the Ocean polygons. This last data set is the linear intersection of all coastal countries with the oceans and therefore represents the coastline of all countries that face the ocean. The coastline length was calculated using Vincenty's equations for geodesic length over the ellipsoidal model of the earth [35,71]. Economic activities can be considered relative to coastline length to provide an indication of the relative intensity of the use made of the coastal ecosystem; in the case of aquaculture, for example, measured in terms of tonnes per kilometer of coastline [1]. For aesthetic purposes, online National Geographic base maps provide the background to Figs. 3–6 [15].

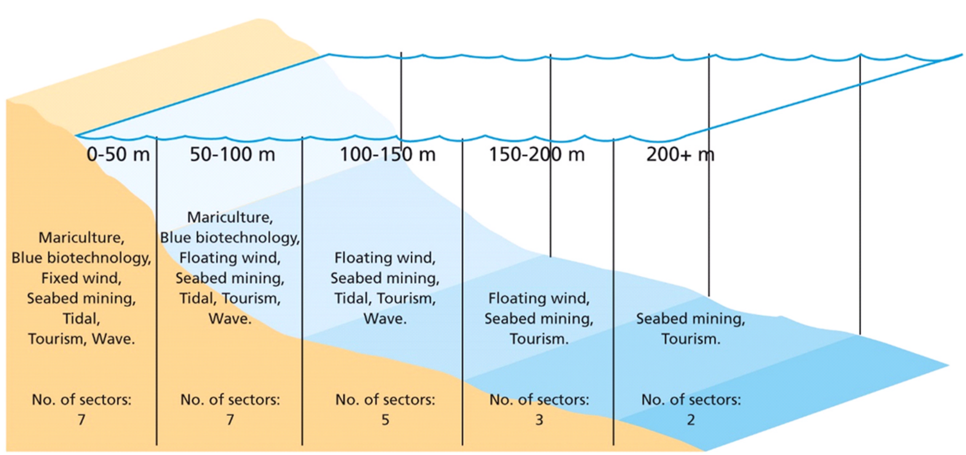


Fig. 2. Operational depth of Blue Growth sectors.

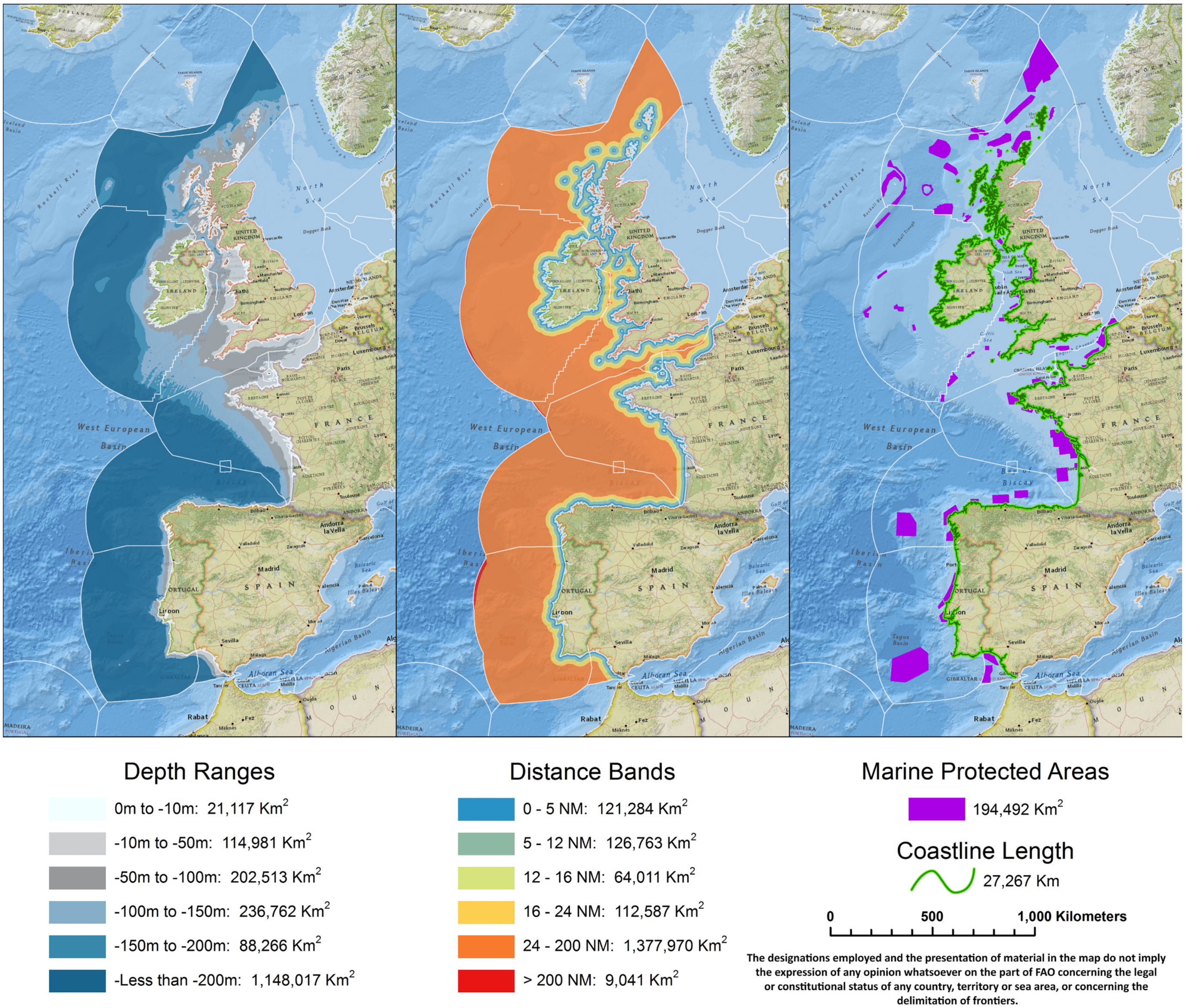


Fig. 3. The European Atlantic Basin, illustrating depth ranges, distance ranges, MPAs and coastline length within EEZs.

3. Results

3.1. What are the operational boundaries required for the Blue Growth industries?

3.1.1. Aquaculture

Offshore Aquaculture may be defined as taking place in the open sea with significant exposure to wind and wave action [13]. Owing to hydrographic conditions, operation and maintenance costs and technical feasibility, aquaculture is bound by depth and distance. Deeper waters and greater distances from shore can be subject to increased wave heights, faster currents and be less accessible for day-to-day operations. Existing technology and costs allow aquaculture installations to be located in areas with water depths between 10 m and 50 m at low tide. The distance from shore at which aquaculture installations operate depends on the technology available to service the installation, and the unique seabed geography of each basin. The maximum cost-effective distance from shore to an offshore aquaculture operation, including Atlantic salmon, was found to be 46.3 km (25 NM) [36,38].

In the future, aquaculture installations are expected to move deeper and farther offshore [38]. In order for such installations to become feasible, there would need to be lower technology and maintenance costs and potentially greater biomass returns. The move offshore can also benefit from clustering of farms, allowing for shared facilities and infrastructure. Industries and MPAs competing for ocean space will affect the potential of the industry [28]. The main challenges in realizing this future state for offshore aquaculture relate to increased governance support, the economic viability of such ventures, and technological advances [41], as well as a maritime spatial planning approach that coordinates the siting of aquaculture facilities to minimize costs and impacts [40].

3.1.2. Offshore wind energy with fixed foundations

Technological advances have made it feasible to install offshore wind farms that take advantage of high wind speeds over water and do not take up space on land. Currently, offshore wind farms use fixed foundations such as monopiles or jackets [6] and are limited by depth of water, distance from shore and hydrographic conditions. The depth boundary is due to technological limitations, including the ability to sink and secure the base of the turbine on the sea floor and enable it to operate economically. Existing technology allows this to occur at depths of up to 50 m. The distance boundary is determined, in part, by

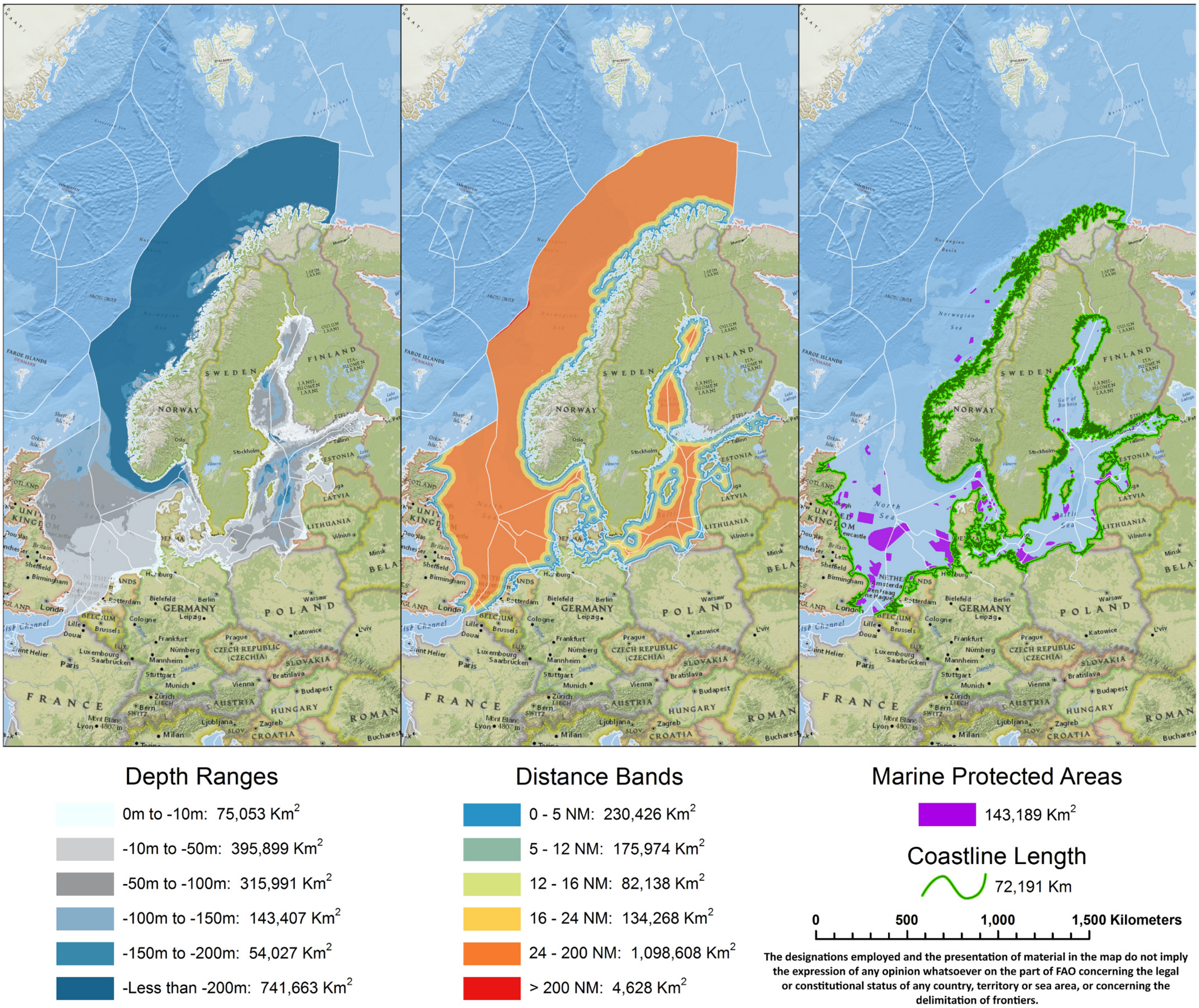


Fig. 4. The Baltic and North Sea Basin, illustrating depth ranges, distance ranges, MPAs and coastline length within EEZs.

the ability to transport the electricity to shore with minimal losses and the need to offset the cost of laying cables. New technology significantly reduces the losses, but these technologies are currently prohibitively expensive. With current technologies, the average distance from shore for fixed wind turbines is 29 km [20].

Future trends for fixed offshore wind farms lie in increasing the size and efficiency of turbines, i.e. turbines with greater than 7 MW (MW) capacity. Turbines with greater capacity allow for a greater density of power produced from installed capacity [20].

3.1.3. Floating offshore wind energy

As with fixed wind farms, the depth and distance boundaries for floating wind turbines are mainly determined by technological and economic limitations. Floating wind installations, where the turbine is mounted on a buoyant structure moored to the seabed, have been under development for some time. Different types of installations are currently being tested [31]. Through the 30 MW Hywind Scotland project, Statoil is deploying 6 MW floating turbines in the North Sea, 25 km off the coast of Peterhead, at a depth of 100 m [65]. Principle Power and EDP developed the WindFloat project off the Portuguese coast in 2011, and these turbines began to produce power in 2012 using 2 MW Vestas turbines [55].

The depth ranges seen now are 60–200 m, but as technology progresses, greater depths will become commercially viable [20]. The distance from shore will likely be greater than that of fixed wind farms, although projects will still be constrained by technology and the efficiency of energy transmission. Development of this sector outside the boundaries of EEZs will create a more urgent need for new international agreements and marine governance.

3.1.4. Tidal and wave energy

Tidal and wave energy – often considered together as “ocean energy” – represent significant potential for electricity production. Ocean Energy Europe estimated that 100 gigawatts (GW) of combined tidal and wave energy could be brought online by 2050, which would represent 10% of Europe's energy demand (SI [63]). Currently, the activities are focused in the Atlantic, with little activity seen in the Baltic, Mediterranean and Caribbean basins where the potential of wave energy is more limited.

Tidal power technologies range from integrated tidal lagoon turbines that take advantage of water level changes, to freestanding turbines in high tidal currents or continuous current areas. Although this

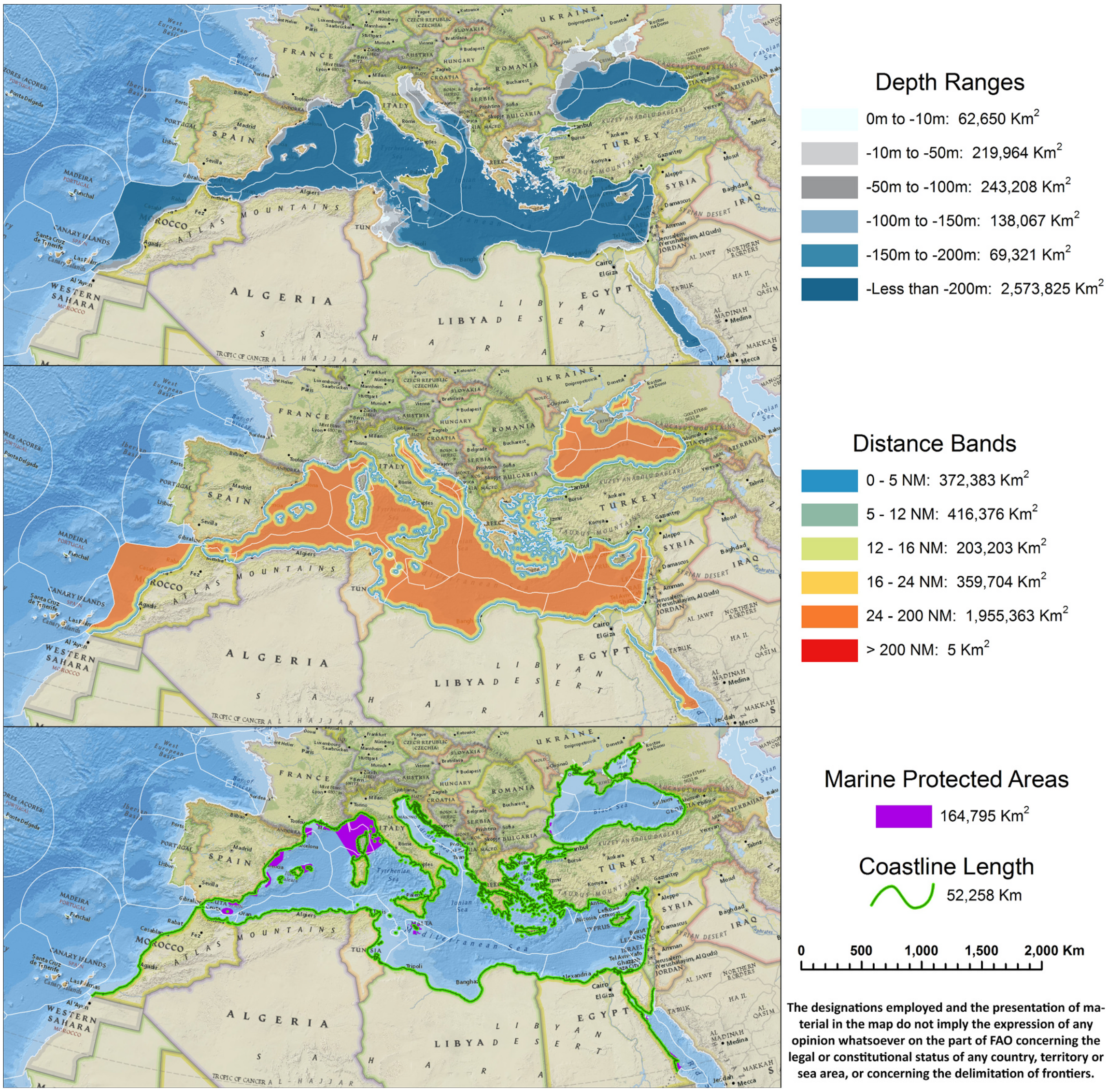


Fig. 5. The Mediterranean and Black Sea Basin, illustrating depth ranges, distance ranges, MPAs and coastline length within EEZs.

technology is not yet widely in use, it has strong potential because of the predictability of the tide and the density of water which produce more power at lower speeds than wind power. However, since deploying tidal technology requires specific hydrographic conditions, it is expected that it will remain a niche market (SI [63]). The challenges with tidal power installations are technical, environmental and related to issues of corrosion, impact on local species and potential fouling. The depth at which tidal installations are deployed depends on the type of device and the method of harnessing power, but generally it is from 25 to 120 m (SI [63]). Presently, the distance of tidal units from shore tends to be quite small, but in the future tidal units could be placed further from shore in areas with strong currents, such as in the Gulf Stream, 100 km off Florida. The depth boundary is mainly determined by the availability of the required environmental conditions, and the economic feasibility of building a tidal pool or a current turbine. The distance metric is similar to the wind distance and is constrained by the loss of power over long distances and the maintenance costs of the units.

The wave power industry requires significant innovation to progress it towards a commercially viable product. At this time, the depth boundary for wave power depends on the device type and method of harnessing power. Currently, units are deployed in waters less than 100 m deep (SI [63]). The most important constraint for wave power is the distance from shore. The distance is constrained by the unit, operation and maintenance costs, ability to moor the units in deeper waters and the transmission of the power to shore. At present the furthest a unit has been deployed is 16 km from shore (SI [63]).

3.1.5. Marine biotechnology

Marine biotechnology is defined as "the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living and non-living materials for the production of knowledge, goods and services" [48]. The essence of the marine biotechnology sector lies in exploring the chemical and biological diversity of seas and oceans. Marine biodiversity is considered be a rich source of novel natural compounds. According to ERA-NET Marine Biotechnology, some of these compounds are already used in food, cosmetics and agricultural, chemical and pharmaceutical products, but their diversity has not been fully characterized and utilized. Further opportunities exist for the use of ocean genetic resources in markets for industrial enzymes, functional foods, cosmeceuticals,[1] biomaterials, bioprocessing and medical devices [30]. Marine biotechnology is

[1] Cosmetics that claim to have medicinal properties.

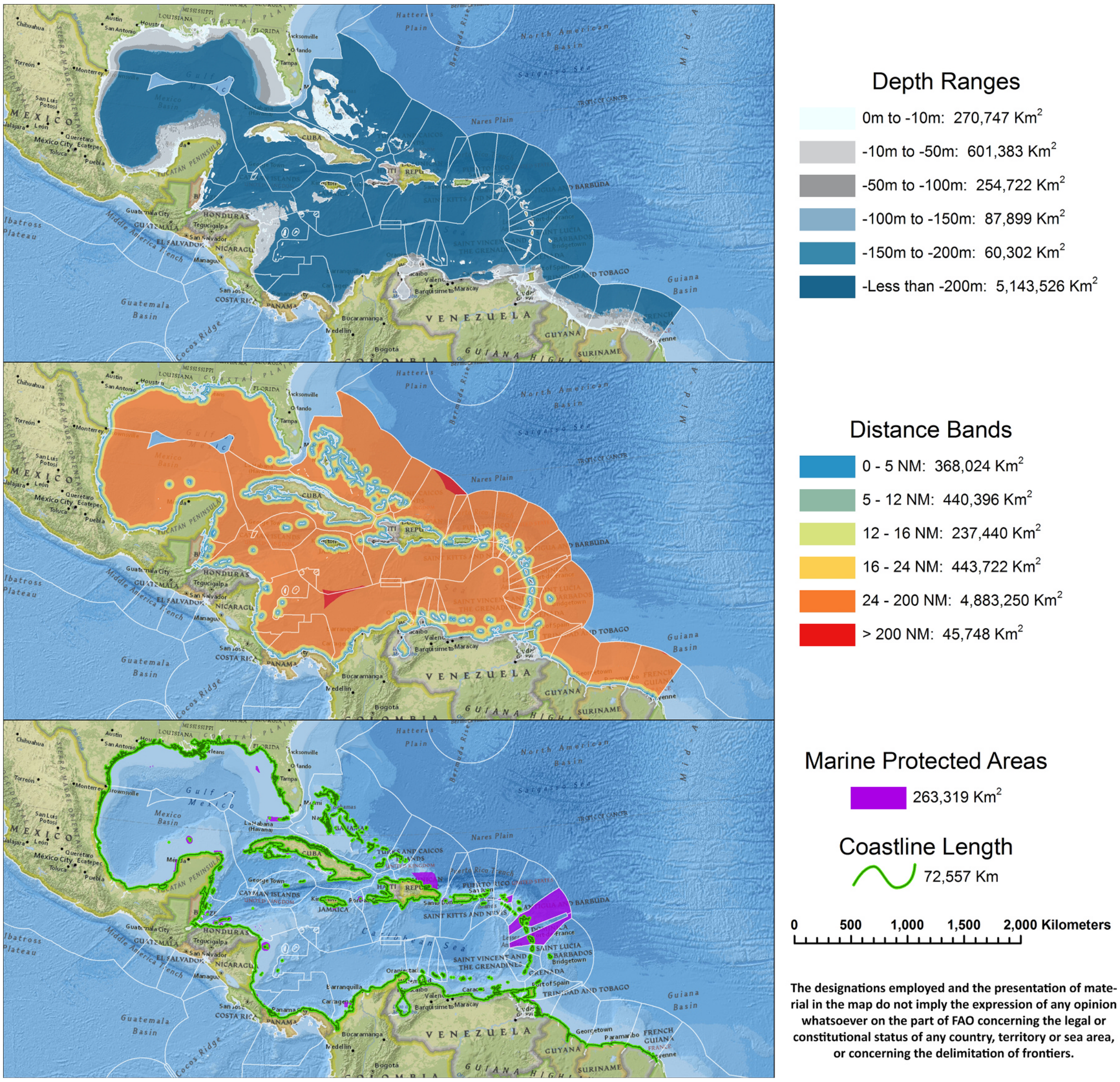


Fig. 6. Caribbean and Gulf of Mexico Basin illustrating depth ranges, distance ranges, MPAs and coastline length within EEZs.

mostly concentrated in the European Union (EU), North America and the Far East. Currently, 90% of all samples taken have been from waters less than 100 m deep owing to the cost of sampling in deeper waters [42]. Distance to shore is rarely a limiting factor.

New technologies are being developed to sample the deep sea for genetic resources. There is a difference in regulations when it comes to accessing genetic resources within EEZs and from ABNJ. The ABNJ is unregulated, which may encourage more sampling in these areas. However, there are few technical innovations that could make sampling far offshore either cheaper or easier. In the long-term, automated underwater vehicles could play an important role in allowing expeditions to take place in deeper water and further from shore. The main barriers for the industry are a lack of coordination and cooperation along the value chain, access to capital, lack of knowledge and insufficient information exchange [42].

3.1.6. Seabed mining

Seabed mining is a complex nearshore and offshore industry, requiring high-level knowledge from diverse fields. This type of mining involves exploration and extraction of minerals other than petroleum from the sea floor, including dredging for sands. More recent seabed mining activities include the mining of ores such as polymetallic (manganese) nodules, polymetallic sulphides (SMS deposits), cobalt crusts (crusts), phosphorites and gas hydrates [5,57]. Each time land-based ore prices rise, interest grows in seabed resources; the opposite happens when prices drop [49,57]. Currently, phosphorites have reached sufficiently high and stable market prices to justify investments in deep sea mining. The other resources remain of geopolitical interest and only a few exceptional cases seem worthy of commercial exploitation. Seabed mining occurs at depths of up to 400 m [57] and it takes place both close to the shore and at greater distances.

Seabed mining technology is being developed to allow for mining at much greater depths in order to access different minerals. Despite technological advances there may not be significant cost efficiencies to be gained in the future because of the exploratory nature of the industry and the lack of consistent economic drive [57].

3.1.7. Tourism and recreation

Tourism and recreational activities vary considerably with depth and distance from the coast. They range from swimming in shallow coastal waters to offshore recreational boating and angling in waters further than 22 km (12 NM) from shore and at depths of a few hundred meters. The diversity of activities contributes significantly to local economies, generating revenue and employment [16]. Offshore structures combined with tourism activities, for example aimed at sport fishing or scuba-diving, could facilitate the combination of industries,

Table 1
Depth and distance boundaries for marine industries.

Industry	Depth (meters)	Present distance from shore	
		Kilometers	Nautical miles
Aquaculture	< 10–50	> 2 (trend up to 46.3)	> 1 (trend up to 25)
Fixed wind	< 50	29	16
Floating wind	60–200	25	13
Tidal energy	25–120	Close to shore	
Wave energy	< 100	< 16	< 9
Marine biotechnology	< 100	Close to shore to deep ocean	
Offshore seabed mining	80–400	Close to shore to deep ocean	
Tourism (including angling)	< 250	< 5	< 3

moving tourism into waters farther offshore and extending the operational season beyond the summer.

Depending on the type of recreational activity, depth and distance will play varying roles in constraining the growth of this sector. Offshore recreational angling, for example, is often restricted by distance from port because of fuel costs and vessel range and finding the optimum conditions to ensure that anglers catch fish [47]. Ensuring good potential for fish capture could assist the growth of this activity. Assessment of the environmental impacts of offshore wind farms has identified them as potential artificial reefs and fish aggregators [76]. Effective management of this combination would benefit recreational fishers, recreational fisheries managers and owners of offshore wind farms [26] at distances ranging from a few kilometers to perhaps 100 km offshore.

The following general conclusions can be drawn from the assessment of operational boundaries for marine industries. Table 1 demonstrates that most marine industries are primarily bounded by depth, although distance from shore is an important constraint. For example, there are distance constraints when considering the transmission of power (energy) produced by wind, tidal or wave energy back to shore, both in terms of cost and energy losses through transportation.

Table 1 and Fig. 2 demonstrate that marine industries overlap in their identified depth bands, which provides scope for multi-use of space for industrial development. In shallower waters there is greater potential for industry cooperation; seven of the Blue Growth (sub) sectors discussed overlap in the 0–50 m band. In the 50–100 m depth band, four (sub)sectors overlap. Beyond 100 m water depth, there is little overlap.

3.2. What areas in the different sea basins are available and suitable for these industries, when considering all areas and when taking into account MPAs?

The following section describes the areas that are available in the four identified sea basins within the EEZs for combinations of industries, based on the identification of overlapping operational boundaries, as described in the previous section. The tables describe the area that lies within all combinations of depth and distance ranges. Results are provided including and excluding areas classified as MPAs because many MPAs are not by definition off-limits for economic activities.

3.2.1. European Atlantic

The Atlantic Basin includes the Atlantic Ocean EEZs of Belgium, France, Ireland, Portugal, Spain and the west coast of the United Kingdom (Fig. 3). Table 2 shows surface areas of the Atlantic Basin that lie within several distance and depth ranges, outside the MPAs.

The total EEZ for this basin is 1811,656 km^2, with 19% of the EEZ less than 100 m deep and 11% covered by MPAs. The total coastline length for the basin is 27,267 km. Large portions of the European Atlantic Basin feature very deep waters, although the depth range varies considerably, even within the waters of individual countries. For example, around the United Kingdom and Ireland waters are less deep than off the Spanish and Portuguese coasts. A small fraction of total sea area features water depths of less than − 50 m (7%). The MPAs are generally located near to the shore, in shallow waters.

3.2.2. Baltic and North Sea

The Baltic and North Sea Basin includes the North Sea, Norwegian Sea and Baltic Sea and spans various countries[2] (Fig. 4). Table 3 shows the area and proportion of the Baltic and North Sea Basin that lie within several distance and depth ranges, excluding MPAs.

The total EEZ for this basin is 1,726,041 km^2, with 46% of the sea area being less than 100 m deep and 8% covered by MPAs. The total coastline length for the basin is 72,191 km. As in the European Atlantic Basin, the MPAs in the Baltic and North Sea Basin are generally located near to the shore and in shallow waters. Proportionate to total basin size, large areas feature water depths between 10 and 50 m. Compared to other basins, distances to shore are generally small, largely as a result of the small and/or narrow shape of the Baltic and North Seas.

3.2.3. Mediterranean and Black Sea

The Mediterranean and Black Sea Basin comprises the Mediterranean and Black seas (Fig. 5) and includes various islands and nations.[3] Table 4 shows the area and proportion of the Mediterranean and Black Sea Basin that lie within several distance and depth ranges, excluding MPAs.

The total EEZ for this basin is 3307,035 km^2, with 16% of the area less than 100 m deep and 5% covered by MPAs. The total coastline length for the basin is 52,585 km. The Mediterranean and Black Sea Basin is much deeper than the previous two basins, although large portions of the basin are situated close to the shore. The areas where depths are more frequently less than 100 m are in Albania, Bulgaria, Croatia, Egypt, France, Greece, Italy, Montenegro, Romania, Russia, Slovenia, Tunisia, Turkey and Ukraine. A large part of the shallower waters are located in the Adriatic and Black seas. The largest MPAs are in the seas around parts of Corsica, Italy, southern France and Spain.

3.2.4. Caribbean and Gulf of Mexico

The Caribbean and Gulf of Mexico Basin includes large areas of the Atlantic Ocean and spans various countries and islands[4] (Fig. 6). Table 5 shows the area and proportion of the Caribbean and Gulf of Mexico Basin that lie within several distance and depth ranges, excluding MPAs.

The Caribbean and Gulf of Mexico Basin is by far the largest basin studied. The total EEZ for this basin is 6418,579 km^2, with 18% of the marine area being less than 100 m deep and 4% covered by MPAs. The seas in this basin are generally deep. Large portions of the basin are more than 24 NM from the shore. There are few MPAs compared to the other basins and they mainly consist of three large MPAs near the

[2] Belgium, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Netherlands, Norway, Poland, Russia, Sweden and the United Kingdom.

[3] It spans Albania, Algeria, Bulgaria, Croatia, Cyprus (North and South), Egypt, France (including Corsica), Georgia, Greece (including Crete), Israel, Italy (including Sardinia and Sicily), Lebanon, Libya, Malta, Morocco, Montenegro, Romania, Russia, Spain (including Balearic Island), Slovenia, Syria, Tunisia, Turkey and the Ukraine.

[4] Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, British Virgin Islands, Bonaire, Cayman Islands, Colombia, Costa Rica, Cuba, Curacao, Dominica, Dominican Republic, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Nicaragua, Northern Saint-Martin, Panama, Puerto Rico, Saba, Saint Kitts and Nevis, Saint Lucia, Saint Vincent, Sint-Eustatius, Sint-Maarten, Suriname, Trinidad and Tobago, Turks and Caicos Islands, Venezuela and US Virgin Islands and United States of America (Gulf of Mexico).

Table 2
Surface area for all combinations of depth range and distance band in the Atlantic Basin. Cell values are area in km^2 [% of Basin].

	0–5 NM	5–12 NM	12–16 NM	16–24 NM	24–200 NM	> 200 NM	Sum
Total surface areas in European Atlantic Basin (showing both km^2 and % of total area for all depths and distances)							
> −10 m	20,523 [1%]	551 [0%]	42 [0%]	0 [0%]	0 [0%]	0 [0%]	21,117 [1%]
10–50 m	59,366 [3%]	34,144 [2%]	9023 [0%]	8373 [0%]	4076 [0%]	0 [0%]	114,981 [6%]
50–100 m	32,246 [2%]	56,219 [3%]	28,264 [2%]	41,942 [2%]	43,842 [2%]	0 [0%]	202,513 [11%]
100–150 m	7884 [0%]	24,939 [1%]	16,235 [1%]	33,001 [2%]	154,703 [9%]	0 [0%]	236,762 [13%]
150–200 m	941 [0%]	6235 [0%]	3365 [0%]	7979 [0%]	69,745 [4%]	1 [0%]	88,266 [5%]
< −200 m	324 [0%]	4675 [0%]	7082 [0%]	21,292 [1%]	1105,604 [61%]	9040 [0%]	1148,017 [63%]
Sum	121,284 [7%]	126,763 [7%]	64,011 [4%]	112,587 [6%]	1377,970 [76%]	9041 [0%]	1811,656 [100%]
Total surface areas subtracting MPAs							
> −10 m	7184 [0%]	248 [0%]	35 [0%]	0 [0%]	0 [0%]	0 [0%]	7468 [0%]
10–50 m	38,108 [2%]	24,651 [2%]	6898 [0%]	6895 [0%]	3841 [0%]	0 [0%]	80,392 [5%]
50–100 m	25,696 [2%]	50,118 [3%]	25,845 [2%]	37,244 [2%]	39,176 [2%]	0 [0%]	178,078 [11%]
100–150 m	6273 [0%]	22,260 [1%]	14,864 [1%]	30,857 [2%]	149,728 [9%]	0 [0%]	223,982 [14%]
150–200 m	766 [0%]	4044 [0%]	2747 [0%]	7424 [0%]	68,201 [4%]	0 [0%]	83,181 [5%]
< −200 m	255 [0%]	4054 [0%]	5984 [0%]	19,616 [1%]	1,005,114 [62%]	9040 [1%]	1,044,063 [65%]
Sum	78,281 [5%]	105,374 [7%]	56,373 [3%]	102,036 [6%]	1,266,060 [78%]	9040 [1%]	1,617,164 [100%]

Table 3
Surface area for all combinations of depth range and distance band in the Baltic and North Sea Basin. Cell values are area in km^2 [% of Basin].

	0–5 NM	5–12 NM	12–16 NM	16–24 NM	24–200 NM	> 200 NM	Sum
Total surface areas in Baltic and North Sea Basin							
> −10 m	69,302 [4%]	4936 [0%]	495 [0%]	266 [0%]	54 [0%]	0 [0%]	75,053 [4%]
10–50 m	99,812 [6%]	87,422 [5%]	30,099 [2%]	37,078 [2%]	141,488 [8%]	0 [0%]	395,899 [23%]
50–100 m	24,801 [1%]	41,090 [2%]	24,074 [1%]	40,744 [2%]	185,283 [11%]	0 [0%]	315,991 [18%]
100–150 m	11,787 [1%]	10,340 [1%]	6853 [0%]	14,304 [1%]	100,123 [6%]	0 [0%]	143,407 [8%]
15–200 m	7992 [0%]	7236 [0%]	3616 [0%]	8924 [1%]	26,259 [2%]	0 [0%]	54,027 [3%]
< −200 m	16,732 [1%]	24,949 [1%]	17,001 [1%]	32,951 [2%]	645,402 [37%]	4628 [0%]	741,663 [43%]
Sum	230,426 [13%]	175,974 [10%]	82,138 [5%]	134,268 [8%]	1098,608 [64%]	4628 [0%]	1726,041 [100%]
Total surface areas subtracting MPAs							
> −10 m	32,565 [2%]	1846 [0%]	153 [0%]	47 [0%]	1 [0%]	0 [0%]	34,611 [2%]
10–50 m	75,220 [5%]	71,788 [5%]	24,989 [2%]	29,686 [2%]	110,853 [7%]	0 [0%]	312,536 [20%]
50–100 m	23,177 [1%]	39,861 [3%]	23,602 [1%]	39,863 [3%]	176,653 [11%]	0 [0%]	303,155 [19%]
100–150 m	11,390 [1%]	9944 [1%]	6741 [0%]	14,000 [1%]	99,202 [6%]	0 [0%]	141,278 [9%]
15–200 m	7850 [0%]	7155 [0%]	3525 [0%]	8649 [1%]	26,079 [2%]	0 [0%]	53,258 [3%]
< −200 m	16,582 [1%]	24,913 [2%]	16,980 [1%]	32,137 [2%]	642,774 [41%]	4628 [0%]	738,014 [47%]
Sum	166,785 [11%]	155,507 [10%]	75,989 [5%]	124,381 [8%]	1,055,562 [67%]	4628 [0%]	1,582,852 [100%]

Table 4
Surface area for all combinations of depth range and distance band in the Mediterranean and Black Sea Basin. Cell values are area in km^2 [% of Basin].

	0–5–NM	5–12 NM	12–16 NM	16–24 NM	24–200 NM	> 200 NM	Sum
Total surface areas in Mediterranean and Black Sea Basin							
> −10 m	50,729 [2%]	9003 [0%]	1637 [0%]	1089 [0%]	193 [0%]	0 [0%]	62,650 [2%]
10–50 m	106,815 [3%]	51,804 [2%]	16,586 [1%]	23,050 [1%]	21,709 [1%]	0 [0%]	219,964 [7%]
50–100 m	80,769 [2%]	66,239 [2%]	22,782 [1%]	30,293 [1%]	43,125 [1%]	0 [0%]	243,208 [7%]
100–150 m	30,155 [1%]	42,483 [1%]	16,422 [0%]	23,171 [1%]	25,835 [1%]	0 [0%]	138,067 [4%]
150–200 m	15,775 [0%]	19,274 [1%]	8961 [0%]	11,612 [0%]	13,698 [0%]	0 [0%]	69,321 [2%]
< −200 m	88,141 [3%]	227,573 [7%]	136,814 [4%]	270,489 [8%]	1850,803 [56%]	5 [0%]	2573,825 [78%]
Sum	372,383 [11%]	416,376 [13%]	203,203 [6%]	359,704 [11%]	1955,363 [59%]	5 [0%]	3307,035 [100%]
Total surface areas subtracting MPAs							
> −10 m	39,840 [1%]	8518 [0%]	1478 [0%]	943 [0%]	193 [0%]	0 [0%]	50,972 [2%]
10–50 m	87,789 [3%]	48,591 [2%]	16,408 [1%]	22,986 [1%]	21,703 [1%]	0 [0%]	197,476 [6%]
50–100 m	67,119 [2%]	58,488 [2%]	20,864 [1%]	28,220 [1%]	42,045 [1%]	0 [0%]	216,736 [7%]
100–150 m	25,133 [1%]	36,697 [1%]	15,070 [0%]	22,214 [1%]	25,047 [1%]	0 [0%]	124,161 [4%]
150–200 m	13,456 [0%]	17,043 [1%]	8562 [0%]	11,355 [0%]	13,515 [0%]	0 [0%]	63,931 [2%]
< −200 m	79,946 [3%]	206,004 [7%]	125,701 [4%]	254,481 [8%]	1822,827 [58%]	5 [0%]	2488,964 [79%]
Sum	313,283 [10%]	375,341 [12%]	188,084 [6%]	340,199 [11%]	1925,329 [61%]	5 [0%]	3142,240 [100%]

Dominican Republic and in the Lesser Antilles.

3.2.5. Country specific maps

The methodology developed in this paper was applied at sea basin level but was also used to generate 72 country-specific maps and corresponding tables to support maritime spatial planning processes at a national level. In Fig. 7a map of the Netherlands North Sea area is provided as an example of the country level maps available as Supplementary materials.

Fig. 7 shows that large parts of the coastline are designated MPAs. For the Blue Growth sectors concerned (in this case, most notably offshore wind and tourism), the distance to shore boundary – rather than water depth – is the limiting factor. Consequently, sectors try to find space in a narrow band across the shore line where competition for

Table 5
Surface area for all combinations of depth range and distance band in the Caribbean and Gulf of Mexico Basin. Cell values are area in km^2 [% of Basin].

	0–5 NM	5–12 NM	12–16 NM	16–24 NM	24–200 NM	> 200 NM	Sum
Total surface areas in Caribbean and Gulf of Mexico Basin							
> −10 m	144,150 [2%]	52,343 [1%]	14,100 [0%]	18,344 [0%]	41,810 [1%]	0 [0%]	270,747 [4%]
10–50 m	96,538 [2%]	107,212 [2%]	52,684 [1%]	87,251 [1%]	257,699 [4%]	0 [0%]	601,383 [9%]
50–100 m	23,339 [0%]	28,012 [0%]	13,603 [0%]	23,893 [0%]	165,874 [3%]	0 [0%]	254,722 [4%]
100–150 m	10,524 [0%]	8292 [0%]	4196 [0%]	7716 [0%]	57,171 [1%]	0 [0%]	87,899 [1%]
150–200 m	7890 [0%]	5781 [0%]	2709 [0%]	3734 [0%]	40,188 [1%]	0 [0%]	60,302 [1%]
< −200 m	85,583 [1%]	238,756 [4%]	150,147 [2%]	302,784 [5%]	4320,508 [67%]	45,748 [1%]	5143,526 [80%]
Sum	368,024 [6%]	440,396 [7%]	237,440 [4%]	443,722 [7%]	4883,250 [76%]	45,748 [1%]	6418,579 [100%]
Surface areas subtracting MPAs							
> −10 m	107,405 [2%]	46,257 [1%]	13,377 [0%]	17,963 [0%]	41,123 [1%]	0 [0%]	226,125 [4%]
10–50 m	79,886 [1%]	98,128 [2%]	50,564 [1%]	86,005 [1%]	255,893 [4%]	0 [0%]	570,476 [9%]
50–100 m	18,416 [0%]	24,218 [0%]	12,942 [0%]	23,632 [0%]	165,687 [3%]	0 [0%]	244,895 [4%]
100–150 m	8216 [0%]	7684 [0%]	3933 [0%]	7564 [0%]	57,001 [1%]	0 [0%]	84,398 [1%]
150–200 m	6333 [0%]	5362 [0%]	2632 [0%]	3612 [0%]	40,112 [1%]	0 [0%]	58,052 [1%]
< −200 m	75,119 [1%]	220,078 [4%]	143,431 [2%]	289,844 [5%]	4197,099 [68%]	45,746 [1%]	4971,316 [81%]
Sum	295,375 [5%]	401,727 [7%]	226,879 [4%]	428,620 [7%]	4756,914 [77%]	45,746 [1%]	6155,261 [100%]

space increases. Marine spatial planning and marine policy must address the question of how to make use of areas further from shore and find ways to increase the distance to shore boundary.

3.3. What are the consequences for development of multiple use combinations and marine spatial planning in the regions concerned?

Having analyzed the sector specific boundaries for the Blue Growth industries (Section 3.1), as well as the available areas in the sea basins concerned (Section 3.2), the feasibility of combining Blue Growth industries is now addressed on an individual basis basis.

3.3.1. European Atlantic

Aquaculture is a growing sector in the Atlantic Basin. Data collected by the EU showed that EU aquaculture sales volumes and value reached 1.3 million tonnes and €4.5 billion in 2014 [62]. Many of the other Blue Growth industries discussed in this paper are yet to achieve commercial-scale operations. Fixed offshore wind farms are being developed along the coasts of various nations [9], while tests of floating wind energy and wave and tidal energy installations have occurred in the Atlantic Basin, e.g., Galway Test Site; Biscay Marine Energy Platform – BIMEP [3,58,78]. Seabed mining in the form of sand and gravel extraction is a large industry [4], marine biotechnology is an emerging industry [54] and tourism is also an active industry across much of the Atlantic Basin [27].

Fig. 3 shows that the shallower waters of the Basin are concentrated around the United Kingdom, Ireland and France. Thus these countries have greater potential, at least spatially, to combine shallow-water marine industries in the Atlantic Basin. The aquaculture, tourism, wave energy and fixed and floating wind energy industries have the greatest potential for cooperation. All these industries are active in the depth band of less than 100 m, and within the distance range of 16 NM. Given the recent surge of activity in the offshore wind energy sector, research efforts on multi-use focus mostly on the combined use of wind farms by other sectors [29,52].

3.3.2. Baltic and North Sea

In the Baltic and North Sea Basin various Blue Growth industries (excluding floating wind, tidal and wave energy) play a role in the marine economy (see, for example, [10]). Aquaculture is an important industry, with Norway producing a significant portion of the world's farmed salmon [24,25] mainly in the Norwegian Sea area. Fixed wind farms are rapidly being developed in the North Sea, in the UK, Dutch, Danish and German EEZs [2]. For the Dutch EEZ alone, these will occupy up to 2900 km^2 in 2023 [46]. Seabed mining, in the form of sand and gravel mining, is a well-established sector and is important for some countries [12,53]. Tourism is also a vibrant sector in the basin [10].

The depth profile of the Baltic and Norwegian Sea Basin makes it suitable for various marine industry combinations. Based on geographical conditions, the industries that have the highest potential for working together are aquaculture, fixed wind energy and tourism. In the context of the rapid development of offshore wind energy – initially driven by strong government support – the development of combinations that include offshore wind energy seems logical. In this context, Jansen et al. [34] and van den Burg et al. [69] highlight the potential for combining offshore mussel culture with wind energy in the Dutch North Sea. This option is currently also being piloted in the Belgian offshore wind farms [33]. The Baltic Sea is characterized by high eutrophication levels that limits the potential for the culture of most fish species. Extractive aquaculture, such as mollusks and seaweeds which remove plankton and nutrients from surrounding waters, may help to decrease high nutrient levels, and thus pave the way for the development of more aquaculture activities in the future [64].

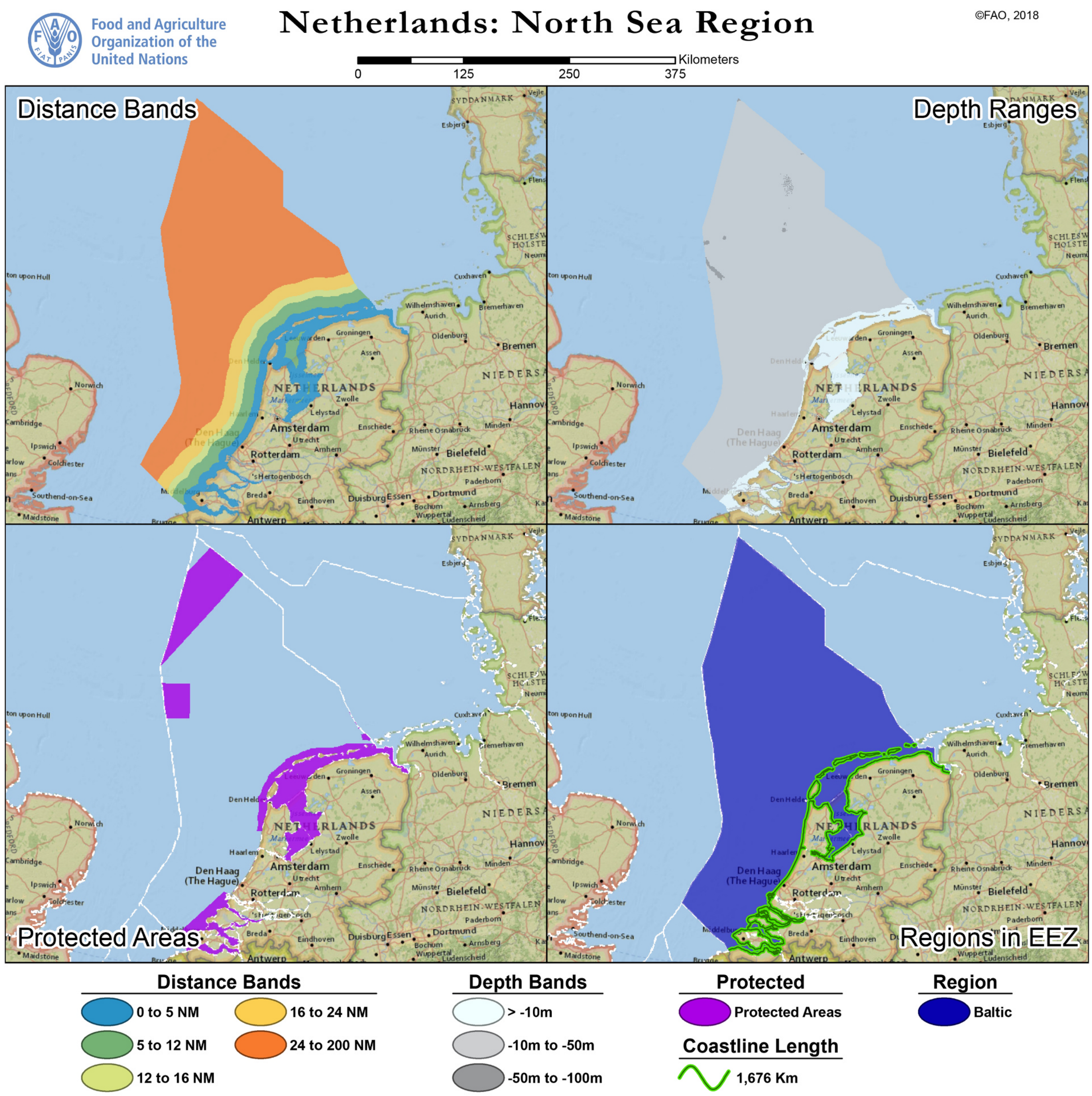
3.3.3. Mediterranean and Black Sea

Neither offshore fixed and floating wind energy, nor tidal and wave energy currently play a significant role in the marine economy of the Mediterranean [17]. Seabed mining has limited potential in this basin but, given that this is an area with high biodiversity [45], there is considerable interest in the potential of marine biotechnology. Eurostat data shows the tourism appeal of the Mediterranean region, with many of the top European tourist sites located in this sea basin, e.g. Cataluña, Iles Balears and numerous Adriatic and Aegean Sea resorts [19].

Although the Mediterranean Basin has some potential to combine offshore wind, marine biotechnology and tourism, (the combination of offshore wind and artificial reefs was evaluated by [74]]), the shortage of areas with depths of less than 100 m (Fig. 5, Table 4) limits this potential. As technologies evolve and industries develop ways of working in deeper waters, there may be increased opportunities in this basin in the future.

3.3.4. Caribbean and the Gulf of Mexico

In the Caribbean and the Gulf of Mexico Basin, aquaculture is an active industry and the FAO predicts a significant expansion of aquaculture production in Latin America and the Caribbean. Production could reach 3.7 million tonnes by 2025, an increase of 39.9% over the level of 2013–2015 [22]. There is also good potential for ocean energy (fixed and floating wind, tidal and wave) but at present none of these technologies are deployed commercially [50]. Marine biotechnology, while not currently active, also has good potential in this region, whereas seabed mining, as in some of the other basins, presently has limited potential [50].



All Areas in Netherlands EEZ: Cell Values = Area in Km² [% Depth Band (Row), % Distance Band (Column), % EEZ]

	0 to 5 NM	5 to 12 NM	12 to 16 NM	16 to 24 NM	24 to 200 NM	> 200 NM	Total
> -10m	5,930 [92%, 73%, 9%]	540 [8%, 10%, 1%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	6,470 [10% of Total]
-10m to -50m	2,212 [4%, 27%, 3%]	4,695 [8%, 90%, 7%]	2,697 [5%, 100%, 4%]	5,409 [9%, 100%, 8%]	41,982 [74%, 99%, 66%]	0 [0%, 0%, 0%]	56,994 [89% of Total]
-50m to -100m	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	309 [100%, 1%, 0%]	0 [0%, 0%, 0%]	309 [0% of Total]
-100m to -150m	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0.000 [0% of Total]
-150m to -200m	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0.000 [0% of Total]
<-200m	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0.000 [0% of Total]
Total	8,142 [13% of Total]	5,234 [8% of Total]	2,697 [4% of Total]	5,409 [8% of Total]	42,291 [66% of Total]	0.000 [0% of Total]	63,773 Km²

Areas in Netherlands EEZ Excluding Protected Areas: Cell Values = Area in Km² [% Depth Band (Row), % Distance Band (Column), % EEZ]

13,599 [21%] Km² Protected	0 to 5 NM	5 to 12 NM	12 to 16 NM	16 to 24 NM	24 to 200 NM	> 200 NM	Total
> -10m	218 [100%, 18%, 0%]	0.272 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	218 [0% of Total]
-10m to -50m	986 [2%, 82%, 2%]	4,471 [9%, 100%, 9%]	2,696 [5%, 100%, 5%]	5,407 [11%, 100%, 11%]	36,221 [73%, 100%, 72%]	0 [0%, 0%, 0%]	49,781 [99% of Total]
-50m to -100m	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	175 [100%, 0%, 0%]	0 [0%, 0%, 0%]	175 [0% of Total]
-100m to -150m	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0.000 [0% of Total]
-150m to -200m	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0.000 [0% of Total]
<-200m	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0 [0%, 0%, 0%]	0.000 [0% of Total]
Total	1,203 [2% of Total]	4,471 [9% of Total]	2,696 [5% of Total]	5,407 [11% of Total]	36,396 [73% of Total]	0.000 [0% of Total]	50,173 Km²

The designations employed and the presentation of material in the map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal or constitutional status of any country, territory or sea area, or concerning the delimitation of frontiers.

Background reference map from National Geographic. Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Projection: Azimuthal Equidistant
Datum: WGS 1984
False Easting: 0.0000
False Northing: 0.0000
Central Meridian: 4.8748
Latitude Of Origin: 53.5526

Fig. 7. Country level maps of the Netherlands North Sea, an example of 72 country-specific maps and corresponding tables developed to support marine spatial planning at national level.

Table 6
Surface area of regions with the highest potential per basin in km^2.

	EEZ (km^2)	< 100 m water depth(%)	< 100 m and < 16 NM(%)	< 100 m and < 16 NM excluding MPAs(%)
European Atlantic	1811,656	338,611 [19%]	240,377 [13%]	178,783 [11%]
Baltic and North Sea	1726,041	786,943 [46%]	382,031 [22%]	293,200 [19%]
Mediterranean and Black Sea	3307,035	525,822 [16%]	406,364 [12%]	349,095 [11%]
Gulf of Mexico and Caribbean	6418,579	1126,852 [18%]	531,982 [8%]	451,193 [7%]

Nine percent of the Caribbean and Gulf of Mexico Basin has waters less than 50 m deep (Fig. 6, Table 5) and these areas are concentrated along the coasts of the Bahamas, Cuba, French Guiana, Guyana, México, Nicaragua, Suriname, Venezuela and the United States of America. These areas have good potential to develop combinations with aquaculture, floating wind energy and tourism. Although tourism cannot be combined well with all industries because of safety concerns, combining it with other industries can serve as an educational tool to increase understanding and acceptance of different industries and combinations of industries.

3.3.5. Geographic potential for the most promising combination: fixed offshore wind and aquaculture

The discussion on current developments shows that the greatest interest in the combined use of space involves the fixed offshore wind energy and aquaculture industries. Aquaculture is an established industry in all four sea basins and offshore wind energy is developing in some of the basins. Both industries operate in areas of limited water depth and relatively close to shore. In Table 6, an analysis is made of available ocean space that meets the following three requirements (1) < 100 m water depth, (2) < 16NM from shore and (3) not part of an MPA.

Relatively large regions of the Baltic and Norwegian Sea meet these criteria, highlighting the geographical potential to further develop aquaculture and offshore wind energy in these areas. In absolute terms, the Gulf of Mexico and Caribbean Basin has a larger area that meets these criteria, but they are dispersed over a larger sea basin.

3.4. What are the main non-operational barriers to the multi-use of sea space?

Getting two or more sectors together in a multi-use arrangement is not only dependent on shared operational boundaries based on depth and distance from shore alone. A number of studies have examined willingness and barriers to cooperate, most often with a focus on combined offshore wind energy and aquaculture. Many studies have identified economic incentives for cooperation, such as shared operations and maintenance (Micler-Cieluch et al., 2009; [56,7]).

Yet, commercially exploited multi-use combinations have not materialized so far. Various reasons for this are identified. Institutional arrangements for cross-sectoral activities are missing and need to be developed [44]. According to Stuiver et al. [66] a clear policy framework to guide multi-use, including a clear licensing procedure, is currently lacking. The recent Safe production Of Marine plants and use of Ocean Space (SOMOS) project focused on a framework for risk assessment that may remove resistance to multi-use (https://www.wur.nl/en/project/SOMOS.htm). A lack of trust between sectors is reportedly an issue of concern, leading to a call for innovative social networks that can help to create trust [67]. The Multi-use in European Seas (MUSES) project is focused on identification of non-operational barriers and formulating a roadmap to remove them (https://muses-project.eu).

The quantitative assessment of potential for multi-use presented in this paper does not solve the issues mentioned above but can be input to discussions within such networks to focus development of required institutional arrangements, overcoming barriers to real-life development of multi-use arrangements.

3.5. How can the methodology developed in this paper support marine spatial planning processes?

Interest by national policymakers in the potential of multi-use combinations is increasing, particularly in Northwestern European countries. Stuiver et al. [66] studied the governance of multi-use platforms at sea. Until now, governance has primarily focused on creating knowledge of the economic, technical and environmental feasibility of combining industries at sea. European research funding has played an instrumental role here, for example, supporting research and innovation. Governmental support for continued research will bring technological innovations that will enable the further development of the Blue Growth industries. Legislation is often seen as a barrier to multi-use. Policies that enable or even require the multiple use of sea space can encourage the development of multiple use approaches. In addition, incentives such as environmental taxes or tax rebates can also boost the multi-use of sea space.

This paper's contribution to the discussion on multi-use is that it illustrates the geographical potential for the combined use of marine space. Based on the analysis, the following challenges for marine spatial planning are identified:

- It is important to recognize the potential of combined use within sea basins by understanding operational boundaries and geographical characteristics. Clearly, the geographical potential for combined use of space differs between sea basins. Most combinations of activities are possible in relatively shallow waters situated not too far from shore.
- Recognizing the potential for certain combinations, policymakers can gear up efforts to bring stakeholders together in innovative social networks, addressing non-operational barriers to multi-use.
- Each marine activity would also need to investigate and consider other limiting factors for marine location, such as shipping and fisheries, plus (in varying circumstances) maximum wave heights, speed of currents, existence of MPAs or military areas, point sources of pollution, fish nursery grounds, etc.
- The combination of offshore wind energy and aquaculture is already a subject of study, which confirms the identified geographic potential of some sea basins. It can be seen as a priority combination – perhaps the first multi-use combination to mature.
- Based on the geographical analysis, there is potential for combining marine industries with tourism, yet there is relatively little interest in combinations that include tourism activities. Although they have been studied to some extent [74,75], such combinations warrant further study.
- Many marine habitats are sensitive to change and Blue Growth should not cause damage to these habitats. In the current marine spatial planning process, establishing an MPA is the most effective way to protect an area. The impact of developments outside of MPAs must be taken into account, particularly where the cumulative effects of combining different sectors are expected.
- Climate change will affect conditions at sea and thereby the feasibility of accommodating (combinations) of sectors. The consequences might be uncertain and vary according to sector, but the marine spatial planning processes need to be adaptive to these changes [60].

4. Conclusion

This article calls attention to the great and widespread potential for the combined use of marine space. Its purpose is to encourage countries with significant absolute or relative potential for the multiple use of marine space to undertake studies at the national level to define that potential as a step towards updating policies and improving planning for the development of Blue Growth sectors.

One of the objectives of maritime spatial planning is to manage ocean resources sustainably. Areas where multiple sectors overlap run the risk of overexploitation and great care must to taken to allocate space within the limits of environmental sustainability. Overlapping operational boundaries do not only point towards the potential for cooperation, they also point towards potential conflict. Where multiple sectors make competing claims for space, there is potential for long-term economic sustainability to be negatively impacted.

In order to develop a governance framework for the developing marine industry combinations, an understanding of the geographical conditions required for marine industries is required. Although all marine industries have their own considerations for site selection, understanding the depth and distance boundaries for each industry provides an indication of where the Blue Growth industries have the greatest potential. The continued growth of the these industries must be supported with marine spatial planning and marine governance that recognizes the potential of multi-use combinations for the basin concerned. The methodology developed here can be suitably configured to provide quantitative inputs to marine spatial planning.

Those areas within 16 NM from the shore and with depth ranges of less than 100 m have the highest potential for the multi-use of sea space. At the same time, these areas are generally characterized by a higher level of activity and therefore have greater potential for spatial conflicts (including access restrictions and conflicts with already existing activities).

Depth and distance from shore for each of the marine industries have been used to define their boundaries. This approach is a preliminary step because there are additional factors that influence the final suitability of marine space for the development of a given marine economic activity. Current speed, exposure, distance to ports (rather than simply distance from shore), seasonal considerations such as ice cover, and weather conditions (such as temperature gradients), water quality and flow, etc. are all factors that may influence development. The manner in which such factors influence the potential for combining industries is not in the scope of this study, but they are an important consideration when exploring marine industry combinations in a country. Factors like these should be studied in more detail. Conflict and opportunity matrixes can be used to facilitate further discussion around the prospects for the multi-use of sea space [43].

With the improvement of existing technologies, a movement towards deeper waters might be expected for most industries, leading to more opportunities for industry combinations and fewer potential spatial conflicts. Moving further offshore and crossing jurisdictional boundaries implies that issues of ownership, rights and responsibility need to be addressed, particularly when activities take place outside the territorial zones.

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Declarations of interest

None

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2018.10.050.

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