THE OCEAN SYSTEM

Adalberto Vallega
First Vice-president, International Geographical Union, Genoa, Italy

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Summary

The ocean has in recent times been involved in unprecedented conditions due to concurrent influences, from climatic change and subsequent changes in biogeochemical cycles to globalization and expanding and intensifying human pressure. The human approach to the ocean is moving from modern conditions, where the ocean ecosystem was regarded as an exhaustible resource reservoir, to postmodern ones, where it has been increasingly regarded as a space for communication, movement, settlement, and esthetic and cultural fruition. The interaction between uses and biotic and abiotic

resources is going to be dealt with through the operation of integrated management patterns. These patterns aim at framing all the essential components of the ocean system, assumed to be an ecosystem with human presence and resources exploitation, into one unique view. The international law of the sea, designing national jurisdiction and regulating international ocean spaces, has become an essential component of this approach. Integration has been pursued also on the geographical scales of management (i.e. global, regional, and local).

1. Introduction

In the early 1990s, a scream of anguish was heard all over the world: the population of coastal areas had increased much more than any other areas. At the end of the twentieth century, about two-thirds of the world's population were living within 100 km of the coastline and the numbers were expected to continue rising. Moreover, the scenarios of climate change and subsequent sea-level rise had filtered through to decision-making systems as well as coastal and island communities. Meanwhile it became evident that the deep ocean was under increasing stress from expanding sea transportation and biomass exploitation, and the expected rise in exploitation of immense mineral resources located in the seabed and subsoil.

These conditions and prospects led to a focus on the need to safeguard the ocean ecosystem as a whole, and particularly its biodiversity, in order to mitigate and prevent stress and to guarantee a sustainable use of its biotic and abiotic resources.

2. Managing the Ocean Ecosystem

2.1. The Tectonic Mechanisms

When focusing on the role of the life-supporting system of the ocean, the marine ecosystem should be approached by considering firstly its main abiotic features, and then some key aspects of its biodiversity. The cardinal aspect of its abiotic organization is the plate tectonic dynamics.

The surface of the earth is composed of a series of rigid and relatively thin (100–150 km) plates that do not necessarily follow the boundaries of the continents. Most of them are composed of both oceanic and continental crust material floating on top of the asthenosphere, a less rigid and more profound part of the crust. Two contiguous plates may interact in three ways.

Divergence of plates: This process is marked by ridges, such as in the mid-Atlantic Ocean, the southern and southeastern Pacific Ocean, and the southern Indian Ocean. Basaltic upwelling at the ocean bed, along the plate boundaries, leads to the formation of ridges with lateral spreading from the ridge towards adjacent areas of the ocean seabed. Hence, divergent plates are "constructive." The energy dynamics of ridges cause earthquakes and volcanicity. Ridges lie along the deep-ocean floors so they have no impact on coastal areas except where islands are located on them (e.g. Iceland).
Convergence of plates: The seabed is marked by trenches where older oceanic crust is subducted back into the lower layers of the crust. Hence, convergent plates are

"destructive." These plates also cause earthquakes and volcanicity but, unlike divergent ones, they have a considerable impact on coastal areas in widespread and important parts of the world including Southeast and East Asia, and the islands and archipelagos of the western Pacific.

Transform plates: Where two adjoining plates move parallel to each other along transverse fractures, but at different speeds and in opposite directions, no crust is produced or destroyed. This motion characterizes transform plates and causes earthquakes. Transverse fractures mark the Pacific coast of North America and, to a variable extent depending on the region, they are associated with coastal seas.Oceans extend between two or more plates, or they originated when a plate was broken. The interface between the continental and the oceanic crusts is the continental margins. Three types of continental margins may be found.

Divergent margins: These margins develop when continents are rifted apart to form new oceans, so that the continent and adjacent ocean floor are part of the same plate. They form at divergent plate boundaries initially by rifting of the continental crust and, with time, move away from these boundaries. They are passive and are not influenced by volcanism and earthquakes. This tectonic situation can be observed in Atlantic European coastal regions including the surrounding semi-enclosed and enclosed seas (particularly in the North Sea and Baltic Sea).

Convergent margins: These mark the boundaries between two different plates, such as in the western Pacific, where the Asian and Pacific plates converge. Unlike the divergent margins, the continental and the oceanic crusts belong to different plates. This is the reason why, as has been mentioned, earthquakes and volcanic activity are common in these areas.

Transform margins: These consist of faults intersecting both active and passive margins. They result from horizontal shear motion between plates, marked by shallow focus earthquakes, and can become tectonically passive.

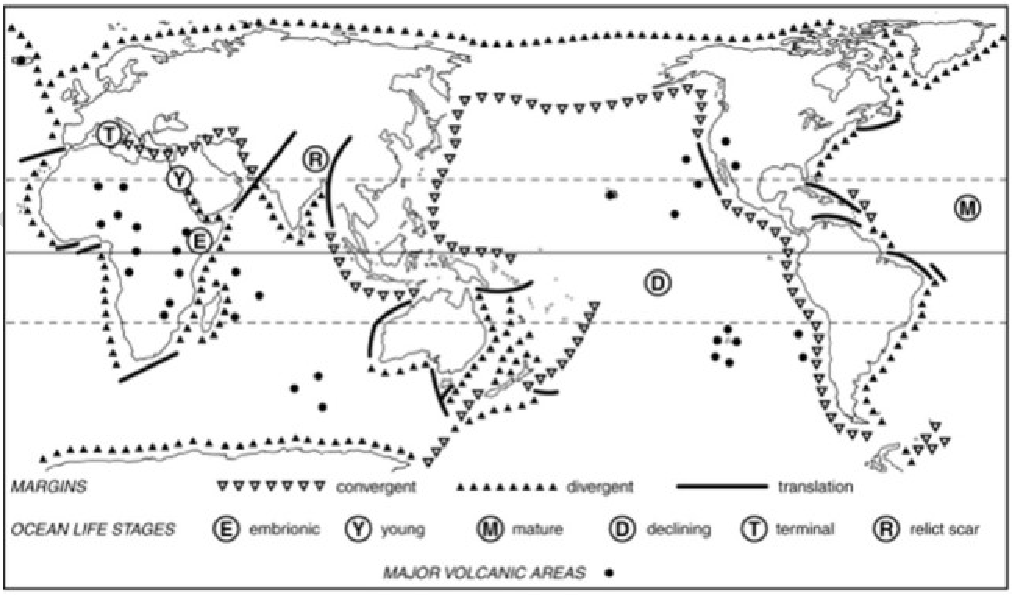

Figure 1. The location of the continental margins
(*Source*: A. Vallega, *Sustainable Ocean Governance. A Geographical Perspective* (London: Routledge, 2001), p. 29)

The continental margins have different morphological characteristics according to the diverging or converging nature of the plate. When plate tectonics is considered for management purposes, divergent plates, marked by passive margins, are seen as useful for representing typical coastal geological structures. In this case, the continental margin includes three sections: (1) the shelf, (2) the slope, and (3) the rise.

Continental shelf: For management purposes, this is the most important part of the margin. It is a shallow, submerged platform serving as the interface between the sea and land. Its global extent is estimated at 27×10^6 km^2, corresponding to about 7% of the whole oceanic area. Shelves comprise the area of the sea bottom between the shore and the shelf break, the line at which the angle of inclination slopes sharply, marking the boundary between the shelf and slope. Most shelves have gently rolling topography. The width of continental shelves varies from a few km to more than 400 km. The depth of the shelf break also varies widely from about 70 m to more than 400 m (off parts of Norway), averaging about 145 m.

Continental slope: This part is located seaward of the outer edge of the continental shelf. Slopes occupy about 9% of the sea floor (28×10^6 km^2) and extend to depths of 4000 to 5000 m.

Continental rise: This part is the transition zone between the continental margin and the deep ocean and consists of immense accumulations of terrigenous sediment deposited by turbid currents and other gravity flows, and of smaller quantities of pelagic sediments accumulated at the base of the slope.

The deep-ocean floor: Seawards from the rise lies the deep-ocean floor, covering 79% of the ocean. Mapping has confirmed the presence of various geomorphologic features: fracture zones, which are genetically different from the trenches characterizing the continental margins of the convergent plates (Pacific Ocean); deep-ocean trenches forming island arcs; seamounts, consisting of submarine volcanoes, guyots (flat-topped seamounts), and abyssal hills. For ocean management, the mid-ocean ridges are the most important physical structures. They are volcanic and seismic, and extend 80 000 km with an average depth of about 2500 m through all the oceans.

2.2. Ocean Governance in Relation to Plates and Margins

The structure and dynamics of plates and margins are especially relevant to ocean governance, particularly to the management of oceanic resources.

Firstly, plates are endowed with different mineral resources according to their type and evolution stage. Deposits of oil and natural gas are distributed on the continental margins. The other major category of resources—manganese nodule deposits—may be found in the deep-ocean beds. The most important deposits have thus been discovered in the Pacific Ocean while the Atlantic Ocean seems to have no abundant resources in this category.

Secondly, the nature and movement of plates influences the geographical distribution of volcanic and seismic areas. The mid-ocean ridges are subject to intense seismic activity and include belts of volcanoes, some of which emerge at the ocean surface. The faults along which the transform plates slide are marked by earthquakes of even greater intensity, such as may be found in the fault system of San Andreas, California, where the Pacific and North American plates interact. Both volcanic and seismic manifestations characterize the trenches, where two plates converge, as found, for example, on the western coasts of Southern and Central America or, more spectacularly, the coasts of Japan and nearby countries. Frequently, the seismic movements in the seabed or massive volcanic eruptions at sea provoke *tsunamis* (i.e. seaquakes, from Japanese *tsu* “harbor” and *nami* “sea”) that affect the continental belts. The compression generated by convergent plates is the major factor contributing to continental seismic manifestations, and can be observed in the significant seismic belt extending from Burma to the Mediterranean.

2.3. The Role of the Water Column

The second abiotic component of the ocean is the hydrosphere. By focusing on the need to optimize ocean governance, attention may be limited to only some physical aspects.

Composition of seawater: The composition of the water column is influenced by human activities in a number of ways. These embrace dumping, accidents, river effluents, land-based sources including urban, manufacturing, and agricultural activities, manufacturing activities at sea, oil and gas exploration and exploitation, ocean mining, and air-transferred materials associated with acid rains. The recycling of chemical substances entering the sea often requires complex chemical and biological processes that may consume marine oxygen. Consequently, impacts from terrestrial and atmospheric human activity may be expressed by the quantity of oxygen required to oxidize the material entering the water column. This justifies using oxygen demand as a primary indicator for measuring the stress the ocean systems undergo in relation to chemical inputs. Two different oxygen demands may be considered according to whether non-organic or organic matter is being conveyed to the sea: the chemical oxygen demand (COD) indicating how much oxygen is needed to oxidize non-organic materials, and the biological oxygen demand (BOD) indicating how much oxygen is required to oxidize organic material. The effects of large quantities of organic matter on aquatic communities may cause the decline of species diversity, an increase in the relative abundance of deposit feeders, the expansion of smaller organisms, and decrease of the larger organisms.

Nutrients, being compounds of carbon, nitrogen, and phosphorus, attract special attention since they can be conveyed to the sea from various land sources, such as agriculture and certain types of manufacturing process. Aquatic systems, including coastal marine waters, can be found in a number of naturally occurring states, ranging from oligotrophic (poor in nutrients) to eutrophic (rich in nutrients). An increase in nutrients due to inputs from human-derived effluents can lead to higher than normal concentrations of plankton and a subsequent decrease in the concentration of dissolved oxygen. Particularly in estuaries, gulfs, and enclosed seas, this process may result in the eutrophication of previously oligotrophic waters, or may reduce the concentration of oxygen in eutrophic water below the necessary thresholds to sustain trophic webs. Hence the need to balance the inputs from coastal activities and the amount of nutrients in coastal waters.

Properties of seawater: Ocean water is characterized by three physical properties: salinity, temperature, and density. In the context of ocean management, only a few considerations may be relevant. The oceans are subject to mixing forces over such a long period that the salt concentration is homogeneous throughout the open ocean. However, since the latest micro-glaciation (18 000 years ago) the water column has probably been receiving more salt than it has lost with the result that salinity has increased. In contrast to salinity, temperature of the water column is marked by temporal and spatial variability that reflects the solar energy the individual ocean areas benefit from, the influences of cyclogeneses, ocean currents, structure of coastal areas, and a range of other factors. As a result, temperature varies according to latitude, depth, and season. Density, expressed in kilograms of materials per cubic meter of water, varies according to temperature and salinity.

This demonstrates how close the interaction between the properties of saltwater has become during recent geological times. Therefore, any change in inputs from external sources (i.e. land-caused increase in nutrients) that influences an individual property of the ocean environment tends to be reflected in changes to other properties. This may result in profound and extensive changes in the hydrosphere as a whole with potential knock-on effects for the biological components of the ecosystem. It is therefore important that ocean management properly assesses and evaluates the chains of cause and effect that arise from inputs to the ocean system both in the context of the natural world and human society.

2.4. Atmosphere–Ocean Interaction

Climate change is expected to have a considerable impact on the ocean due to the interaction between the atmosphere and the ocean water surface and columns and will influence both the ocean properties and circulation. Ocean circulation consists of two parts: wind-driven circulation, caused by the interaction between the dynamics of the atmosphere and that of saltwater; and thermohaline circulation, consisting of vertical water movements where links between the atmosphere and saltwater are only indirect and mainly caused by vertical density variations. To some degree, these circulation patterns are interrelated because the action of winds on the ocean surface influences both the horizontal and vertical movement of water. Interaction between atmospheric and ocean circulation may be explained by two physical laws. Firstly, there is the Coriolis acceleration by which the earth's rotation about its axis causes moving particles to behave in a way that can be understood only by adding a rotationally dependent force. It causes both atmospheric and oceanic currents to be deflected to the right in the northern hemisphere and to the left in the southern hemisphere. Secondly, there is the Ekman principle, by which the energy impacts exerted by winds on the ocean surface layers are proportional to the square of the wind speed and the direction of the wind.

Wind-driven currents: When considering surface layer circulation, which primarily undergoes atmospheric changes, emphasis shifts to the horizontal plane. In this respect, equatorial currents, sub-tropical and sub-polar gyres, and the Antarctic circumpolar current (and the respective interaction of these with regional currents) form the key geographical areas to which governance issues should be addressed. At regional and local scales, more complicated variable systems of currents may be found. Those most relevant to ocean governance pertain to enclosed and semi-enclosed seas, marginal seas, and any other marine spaces, such as gulfs and bays, that have the potential to influence existing or proposed coastal management programs.

Thermohaline currents: The vertical transfer of saltwater essentially results from differences in density associated with the different layers of the water column. These differences are closely linked, in their turn, with the combined effects of variations in salinity and temperature. In general, during the winter season cooling of surface waters through evaporation leads to an increase in density and a propensity to sink. Convection currents form as a result of downwelling, where cold, dense water sinks until its density corresponds to that of the surrounding water. At this point, a corresponding upwelling takes place, as water ascends to replace that which has sunk, until a dynamic equilibrium is reestablished. The characteristics of this convective water overturning process throughout the world's oceans differ according to various factors, particularly latitude. Significant variations may be found, for example, between the northern and southern hemispheres.

Economic relevance: It is generally acknowledged that the localized abundance of living resources within the marine environment depends on a wide range of physical and chemical factors. Local abundance can occur in those areas where cold and warm currents interact such that intense and extensive upwelling takes place. The particular relevance of this to ocean governance can be found in the chain of cause and effect that has emerged as a result of the study of climate change. Atmospheric warming brings about changes in the patterns of atmospheric circulation; this in turn brings about changes in the patterns of ocean circulation, with concomitant effects on the abiotic components of both large-scale and localized ocean ecosystems. Consequently, this will inevitably result in a significant change in the geographical distribution of living resources in the ocean.

2.5. Ocean Ecological Diversity

When attention shifts to the organic components of the ecosystem, it should first be noted that, at present, the ocean is supposed to host at least 15 000 species of fish and 15 000 to 20 000 species of algae. This enormous ecological and economic patrimony is marked by high diversity at all of the three levels regarded by the U.N. Convention on Biological Diversity as being of major importance:

(a) genetic diversity, concerned with the populations and individuals included in the individual species;
(b) species diversity, concerned with the number of species within an individual ecosystem; and
(c) ecosystem diversity, concerned with the number of ecosystems coexisting in an individual area.

Ecological ocean diversification: When diversity is regarded as the grounds for understanding the interaction between the ocean ecological context and human communities, a chain of relationships should be considered. This chain brings about ecological ocean diversification, and it encompasses the interaction between the individual ecosystems, each endowed with its own species and genetic diversity, and the human communities, each employing its own strategy and technology.

Ocean diversification varies according to the biotic and abiotic components of the ocean ecological reality.

As far as the biotic component is concerned, the cardinal characteristic is that the ocean biomass mostly involves the continental shelves, particularly those of the boreal temperate latitudes, where about 50% of yield is located. As a result, the continental shelves have constituted the marine environments where fisheries and fish farming have extended in all forms. Technological advances lead to expanding catchments seawards, therefore involving the continental slope and rise, and deep-ocean areas. Due to the construction of open-sea installations, fish farming is also expected to expand seawards.
With regard to the abiotic component of the ocean ecosystem, it should be noted that the exploitation of oil and gas has essentially involved the continental shelves and the marginal slopes. It has been concentrated in marginal, enclosed, and semi-enclosed seas, especially in the Gulf of Mexico, Gulf of Maracaibo, the Persian Gulf, Southeast and East Asia, and in the European marginal seas.

When the use of biomass and the exploitation of oil and natural gas are jointly considered, two spatial gaps come to the fore: (1) a gap between the inter-tropical and the temperate ocean latitudes, the latter being much richer; (2) a remarkable gap between the austral and boreal temperate latitudes, the northern latitudes being much richer than the southern.

3. The Ocean Facing Climate Change

3.1. The Hydrological Cycle

The interaction between the ocean and the atmosphere is a main part of the hydrological cycle, which is the sequence of paths followed by water passing between the land, the atmosphere, and the ocean, and between gaseous, solid, and liquid states. In terms of ocean governance, it is useful to bear in mind that this cycle consists of three main processes: evaporation, precipitation, and residence in land and marine reservoirs. Some 496 km^3 of water evaporates from terrestrial and ocean surfaces annually, remaining 10 days in the atmosphere, on average, before falling again as rain or snow. The residence time of the ocean, defined as the time between the addition of water to the ocean and the loss of it, is on average some 37 000 years. Essentially, the dynamics of the whole hydrological cycle are driven by solar radiation and atmospheric temperature.

The crucial question is how the hydrological cycle has evolved and what changes are to be expected in the medium and long term. This question is important because the ocean is especially sensitive to variations in this cycle. Since the last micro-glaciation period (18 000 years ago), the sea level has undergone numerous spatial and temporal fluctuations; variations that since the industrial revolution have been additionally influenced by human communities. Scientists are interested in determining the possible sea-level response to global change in the medium and long term. To deal with this question, changes in global climate over the nineteenth and twentieth centuries have been examined with a view to predicting changes that may occur due to increasing levels of greenhouse gases in the atmosphere. During the twenty-first century the atmospheric temperature is expected to increase by 3°C to 4.5°C, with an expected increase in the range 0.5°C–1.4°C over the medium term (to 2030). This warming rate has been estimated to be between two and seven times faster than the warming that occurred during the twentieth century.

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Biographical Sketch

Adalberto Vallega is professor of urban and regional geography, and coastal management, at the University of Genoa, Italy. In the context of the Italian geographical milieu, he was the president of the Association of Italian Geographers (1981–1984), a member of the executive committee of the Italian Geographical Society, and a chairman of the Italian Committee for the International Geographical Union (IGU). In the context of the IGU, he founded first the Study Group on Marine Geography, and then the Commission on Marine Geography. In 1996, he was elected vice-president of the IGU. In this role, he promoted the *Oceans 21—Science for Sustainable Use of Ocean and Coastal Zones*, a cooperative program convened by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the IGU to implement interdisciplinary research on deep-ocean and coastal management. He was an IGU representative at the UNESCO World Conference on Science (1999). In 2000, he was elected first vice-president of the IGU and a member of the executive committee of the IGU Home of Geography. Recently, he was honored by the University of Nantes, France, for his contribution to the implementation of ocean science.

Professor Vallega's publications include 40 books, one-third on marine subjects, and 280 articles. He has served as associate editor of the journal *Coastal and Ocean Management* and as a board member with other international journals, including *Marine Policy*, *Journal of Marine Systems*, and *Journal of Cultural Heritage*.