EFFECTS OF GLOBAL WARMING ON MARINE ECOSYSTEMS

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Summary

Marine ecosystems are very diversified and involved in a complicated net of internal and external intercommunications. Their evolutionary history and present adaptive possibilities strongly depend on variability of climate conditions. Ocean basins in equatorial, tropical, and moderate zones are distinguished by the stability of environmental parameters and less affected by climatic anomalies. On the contrary, polar oceans were the arena of significant ecosystem changes in the geological past, and their response to natural and anthropogenic impacts is essential in many respects. Global warming as a whole is favorable for primary production and therefore for increase in biological productivity on all ecosystem levels. However, other anthropogenic impacts, such as overfishing and marine pollution, act in the opposite direction, so future changes of marine ecosystems will depend mainly on human activity aimed at environmental protection and resource management: aquaculture, introduction of new species, legislative regulation of fishery, and prevention of marine pollution.

1. Introduction

The stability of the earth's climate and continuity of life on earth in the course of its geological history are supported by the ocean water mass. It provides sustainable physical and chemical conditions for marine organisms and moderates the climate of the continents, making it suitable for life support. The most productive terrestrial ecosystems are located in the oceanic sectors of continents, exposed to the heat and moisture transfer from the ocean with atmospheric currents. At the same time, even relatively small changes of the ocean's physical state may cause significant fluctuations of land climate and ecosystem parameters.

The present global warming trend is understandably discussed mainly from the "terrestrial" point of view. Land, contrary to marine, meteorology adopts long and comparable series of observations. Various manifestations of warming are more numerous and evident on the continents than in the ocean. Land industrial and agricultural activity depends significantly on climate fluctuations, so all long-term economic forecasts must take into account climatic variability and trends.

The "marine" approach to the problem of global warming is different in several aspects. First, the fact itself needs additional proofs because the present system of meteorological and deep-water hydrological observations in the ocean is insufficient to make definite conclusions. It is especially important for the Arctic Ocean where climatic anomalies in the past were more prominent and led to more serious ecological sequences. Second, marine ecosystems in general are more specialized, their trophic structure is more complicated and cycles of organic matter more dynamic than those of terrestrial ecosystems. This means that ocean organisms are rather sensitive to environmental changes. Humankind is interested mainly in representatives of upper levels of marine ecosystems (marketable fishes, sea mammals), but biological productivity of the ocean is determined primarily by mass plankton species that react immediately to all environmental changes. Third, owing to the uniformity of physical and chemical conditions on the wide ocean areas, the geological history is more understandable and permits the reconstruction of past climates and ecosystems more definitely than on the continents.

In this article the present state of knowledge of marine ecosystems and their dependence on global climate changes will be stated. It is also necessary to pay attention to other anthropogenic impacts determining the present and future state of marine ecosystems and biological resources with the changing climatic background: fishery, marine pollution, and aquaculture.

2. The Ocean and Global Climatic Trends

The importance of oceanographic factors for the global climate is connected with the unique physical properties of sea water. It exceeds almost all other substances in thermal capacity. Taking into account the volume of ocean water mass (about 1370 billion km^3), even small deviations of water temperature from its average values, of the order of 1°C and less, may cause significant anomalies of air temperature. However, processes of heat exchange between the ocean and atmosphere are complicated by vertical and horizontal circulation of water masses. During the warm season of the year the heated upper layer is mixed with colder deep water by waves and currents. This circulation extends to depths of about 100 m, while deeper layers conserve relatively low temperatures (from –1.9°C in polar oceans to 3°C–4°C in equatorial and tropical areas). The cooling processes in the ocean differ significantly from those in freshwater basins. The fresh water reaches its maximum density at the temperature 4°C, so the mixing between surface and deep layers ceases when this value is reached, and freezing starts at the temperature of 0°C. The freezing temperature of sea water with average salinity of about 35 mg/liter is equal to the temperature of maximum density (–1.9°C). Therefore the mixing between cooled surface and relatively warmer deep water continues till the whole water thickness become thermally uniform, and surface freezing is hindered until then. The heat release to the atmosphere during this process is one of the main factors that stabilize climate conditions.

Horizontal circulation in the ocean leads to redistribution of heat between tropical, moderate, and polar climatic belts. It depends to a considerable extent on configuration of ocean basins and therefore on water exchange between low and high latitudes. The well-known contrast between climate conditions of northern Europe and northeast Asia is caused mainly by a difference in schemes of oceanic currents: the North Atlantic current, that is the part of Gulf Stream system, penetrates freely into the Arctic basin and has a warming effect on all west Arctic seas, whereas only a little warm Pacific water can reach the Arctic basin through the narrow and shallow Bering Strait. This difference has a significant influence on species composition of the Arctic Ocean.

The most dynamic and significant changes of marine climatic conditions are connected with glacial processes. In the recent geological past (about 10 000 years ago) northern parts of Europe and North America were covered by ice sheets that extended to the polar basin and partially blocked the water exchange between the Atlantic and polar oceans. The contemporary Arctic marine ecosystem as a whole was formed in the course of the last deglaciation that occurred 8000 to 13 000 years ago. All geographical and biological phenomena in the polar seas affected by glaciation are called marine periglacial. In the opinion of some meteorologists, the present climate stage can be defined as interglacial, and a new glacial period is inevitable. However, this viewpoint is not so popular now, as the notion of a global warming trend prevails.

Living organisms in the Arctic Ocean, Antarctic waters, and many Atlantic and Pacific seas are adapted to the ice cover and its seasonal changes. An area of about 8 million km^2 in the Northern Hemisphere is covered by pack ice all year round, and of about 15 million km^2 by seasonal ice of either forms. The variability of ice conditions is in sharp contrast with the relatively uniform marine environment in ice-free areas, and the existence of all species, from microorganisms inhabiting sea ice to sea mammals (polar bears, seals, and others), is affected essentially by this factor.

The very important feedback in climate systems is connected with land and marine ice cover. Snow and ice reflect back into the atmosphere and outer space a much greater part of incoming solar radiation than does any other kind of surface (water, soil, vegetation). Therefore, continental ice sheets and sea-ice cover, once they have formed, tend to self-sustain and expand (the real mechanism is more complicated, but this explanation is quite correct as a first approximation). On the contrary, the restoration of ice cover in the case of deglaciation would be hindered by the increased absorbing capacity of an ice-free surface. Total or partial disappearance of ice in the Arctic Ocean is considered one of the most important possible sequences of global warming. Decrease of river runoff from Eurasia and North America caused by less precipitation and growth of anthropogenic losses would act in the same direction because the input of freshened water to the Arctic Ocean provides favorable conditions for ice formation. It is impossible to estimate all of the ecological sequences of these processes without a clear understanding of Arctic marine ecosystems.

3. Marine Ecosystems

Living organisms and their environment are forming the planetary ecosystem where energy and substance flows are organized into biogeochemical cycles. The ocean, in its turn, represents the macroecosystem that is not isolated from land ecosystems but has specific features of its own. Any ecosystem includes four main structural components: abiotic substances; autotrophic organisms or producers; heterotrophic organisms or macroconsumers; and saprophytes or microconsumers. All living organisms are connected by trophic ties, and several trophic levels can always be distinguished in a concrete ecosystem. Producers constitute the lowest level where organic matter is created from the inorganic by photosynthesis. These processes take place only in the upper layer of the ocean from the surface to a depth of about 100 m, where the penetration of light becomes negligibly small. This layer, also called the euphotic zone, is the most sensitive to climate changes. About 90% of organic matter that supports life activity in the ocean is formed here and then distributes in the water thickness from the surface to the bottom.

Another important mechanism of primary production is chemosynthesis, which supports very specific bottom ecosystems in rift zones where hot and highly mineralized water is effused from the entrails of the earth. This phenomenon was discovered not long ago and attracted heightened interest of biologists and oceanographers. Another type of ecosystems inhabiting areas of cold methanol and hydrogen sulfide bottom seepings was found later. Chemosynthetic marine ecosystems are wholly independent of atmospheric processes.

Macroconsumers are arranged on upper levels, and can be divided into primary, secondary, tertiary, and so on trophic levels depending on the prevailing kind of organisms constituting their nutrition. Marine organisms usually are more specialized than those on land, and five to six trophic levels are typical for marine ecosystems (phytoplankton; zooplankton; planktivorous fishes; carnivorous (piscivorous) fishes; and sea mammals). Humankind also must be considered the upper level of the trophic chain because it consumes no less marine biological resources than do other groups of consumers.

Saprophyte organisms close biogeochemical cycles by decomposing dead organisms into simple inorganic substances. These processes take place mainly in the water thickness and on the surface of the bottom. Mineral remnants of organisms for the greater part are buried in bottom sediments and are not involved in further exchange of matter.

Ocean ecosystems are subdivided according to their spatial position into littoral (coastal), pelagic (connected with offshore water masses), and benthic (of the sea bottom). The same subdivision is applied to ecosystems of coastal seas, isolated to a greater or lesser extent from the ocean. They are often more dependent on land environmental factors (continental air masses, freshwater and mineral runoff) than on adjoining ocean areas. The difference between pelagic and benthic organisms is not absolute because some species inhabit the pelagic zone in the larvae stage of their development and settle on the bottom in the adult state.

Estimates of the total biomass of the ocean differ, but it is generally acknowledged that its value does not exceed 1% of the land biomass. However, the rate of its production is several orders more in the ocean than on continents: in particular, the ratio between annual production of marine phytoplankton (microalgae) and its biomass is about 300:1 whereas the average corresponding value for land vegetation is 0.07:1. A high rate of plankton reproduction permits the support of considerable biomass of organisms on upper trophic levels (see Table 1).

Ecosystem group	**Biomass (billion tons)**	**Annual production (billion tons)**
Microalgae	1.5	550
Animals	32.5	56

Source: K.M. Sytnik et al., *Biosphere. Ecology. Nature Protection* [in Russian] (Kiev: Naukova Dumka, 1987).

Table 1. Comparative values of global biomass and annual production of main marine ecosystem groups

Ocean areas differ significantly by their productivity. In general, coastal and estuarine waters are the more fertile. At the same time, the main environmental parameters (water temperature, total salinity, and chemical composition) are far more variable in the coastal zone than in offshore areas. Climate changes together with chemical pollution, decrease of freshwater runoff, and other anthropogenic impacts may cause negative effects in the first place in these parts of the ocean.

The evolutionary history of marine ecosystems depends on the geological past of different parts of the ocean. Environmental conditions in tropic and moderate ocean zones underwent no significant changes during a period of the order of at least several tens of millions of years. On the contrary, marine ecosystems of high latitudes (North Atlantic, Arctic Ocean) are dynamic and relatively young in geological timescales. Radical environmental changes represented by alternation of glacial and interglacial epochs occurred here during the Quaternary geological period. Würm glaciation, last in the sequence of glacial periods, reached its maximum approximately 18 000–20 000 years ago, and finished about 10 000 years ago. Glacial periods were accompanied by total disappearance of littoral ecosystems in the western Arctic (they were replaced by ridges of shelf glaciers) and an oppressed state of pelagic ecosystems. Even the containing capacity of the Arctic Ocean essentially decreased because a huge mass of water was tied up in ice sheets, and sea level was more than 100 m lower than at present. The response of marine ecosystems to these environmental changes will be shown below, but first we must consider the present environmental conditions affecting the distribution and diversity of marine organisms.

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Biographical Sketch

Gennady Grigorievich Matishov, born January 1, 1945 in Primorsky Krai (Territory), Russia, graduated from the Geography Faculty of Rostov University in 1967. Since then he has lived and worked in Murmansk. Until 1981 he was a researcher in the Polar Institute of Fishery and Oceanography (PINRO) and from 1981 he has occupied the position of director of the Murmansk Marine Biological Institute of the Russian Academy of Sciences (Kola Science Centre). In 1990, he was elected a corresponding member and in 1997 he was elected a member of the Russian Academy of Sciences. He has been a professor of the Murmansk State Pedagogical Institute since 1990.

Professor Matishov has headed and participated in numerous research projects in the fields of marine geomorphology and paleoecology, ecosystem and resource studies of West Arctic Seas, radioactive pollution in the Arctic, environmental assessments, and monitoring. He also participates in a number of scientific councils (International Arctic Science Committee, Russian Geographical Society, Russian Academy of Sciences Council on Arctic and Antarctic Researches), editorial boards, and environmental organizations, and occupies the official position of advisor to the governor of the Murmansk District on science and ecology. He is married to Lyudmila Matishova and they have one son (Dmitry Matishov, b. 1966).