PROPERTIES OF OCEANS, INLAND SEAS, COASTAL ZONES AND ESTUARIES: BIOLOGICAL PROPERTIES

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Summary

The article is introduced by consideration of the basic abiotic parameters in the Ocean that influence marine life. The water column is populated by planktonic (passive) and nektonic (actively swimming) animals, and the sea floor is inhabited by the benthos, living in (infauna) or on (epifauna) bottom sediments. Marine organisms are very diverse; most animal groups are more diverse in seas than on land. Marine ecosystems are based on organic matter created by producers in the course of photosynthetic (the great majority) or chemosynthetic processes. Quantitative distribution of life makes possible consideration of the biological zonality of the Ocean. Zonality is prominent in the water column and on the sea floor and may be geographical, circum-continental, and

vertical. Faunistic differences in marine life account for the biogeographic zonality that is considered for the water column and sea floor. The number of biogeographic provinces decreases from the surface to the deep sea. Inland seas vary in abiotic characters; some of them are populated by communities vulnerable to the invasion of intruders and anthropogenic stress. Estuaries are very important in near-shore communities and serve as “nurseries” for many species.

1. The Ocean

1.1. The Ocean as a part of the Earth biosphere

The Ocean is the largest biotope on Earth and includes the main bulk of the biosphere. Its area is 361.26 million km^2, i.e. 70.8% of the Earth surface. The stock of ocean water is 1340.74 million km^3, i.e. 96.5% of the planet’s total water volume (including that in the atmosphere). The average depth of the Ocean is 3.711 km. Most of the ocean bottom (73.8%) is situated at depths between 3000 and 6000 m and living organisms there are at a very low density.

At the same time, the area of the richly populated continental shelf zone (0 to 200 m) is only 26.5 million km^2, i.e. 7.3% of the total area. The largest are the shelves in the Arctic Ocean (39.6% of total area). In the Pacific Ocean the shelves play a minimal role (only 4.6% of the total area, although the absolute area is the greatest and reaches 8.16 million km^2). The water volume above the shelf is 5.2% for the Ocean on average; in the Arctic Ocean this value reaches 12.2%, while in the Pacific Ocean it falls to 4.9%, although again the absolute volume is the highest, at 34.92 million km^3. The inflow of river waters bearing both favourable nutrients and harmful products of anthropogenic pollution is very important for oceanic and marine life; this total flux is estimated as 46 930 km^3 per year, i.e. only 0.0035% of the total oceanic volume.

The biosphere is an interacting unity of two basic subsystems: the sea and the land subsystems. The former is much older. Even by the beginning of the early Proterozoan age (2.5 billions years ago), various photosynthetic organisms (cyanobacteria) had become well distributed in the ocean.

At the end of this age (the Vend period: 570-680 million year ago) the oxygen concentration had increased to 10^{-2} of the recent value (Pasteur's point) and numerous higher algae and multi-cellular animals appeared. Their metabolism was based on consumption of oxygen from the environment.

As a consequence of geological processes, rapid oxygen accumulation in the atmosphere occurred, leading to an "explosion" of highly organised life on Earth. Even by the very beginning of the Cambrian period (600 millions years ago) almost all currently known animal phyla and classes had appeared and the oceanic biosphere, not too dissimilar to the modern one, was formed.

All subsequent changes in oceanic biota were mainly influenced by geographical and ecological changes related to continental drift and marine transgressions and regressions.

1.2. Basic ecological groups of the oceanic community

There are two principal biotopes in the ocean: the water column (pelagic zone) and the bottom (benthic zone). The community of the water column is divided into two basic ecological groups: the plankton (drifting animals) and the nekton (active swimmers).

Planktonic animals are those drifting with oceanic flows and not able to move horizontally over significant distances or to cross the borders of water masses. However, many of them can migrate vertically over distances of tens and hundreds of meters, moving between different water layers, and experiencing environmental changes (illumination, temperature, density, oxygen concentrations, etc.). Generally, plankton consists of small organisms from fractions of micrometer (μm) to about a centimeter long. In terms of size, plankton may be divided into pico- (<2 μm), nano- (2-15 μm), micro- (15-200 μm), meso- (0.2-30 mm), and macroplankton (3-15(20) cm). Some of larger animals are also regarded as plankton, like medusas >2 m in diameter, pyrosomes >10 m long, and Molid fishes up to 800 kg in weight.

The group of planktonic animals related to the water surface or dwelling near the water-air interface
are considered as a special ecological group and are called neuston.

In terms of taxonomic composition, the plankton is divided into bacterio-, phyto-, and zooplankton. Some fungi (considered to be a separate kingdom) are also present in the water column, but our knowledge of this group is very scant. The main bulk of the phytoplankton is unicellular algae 1 to 2000 μm long, but drifting multicellular algae like Sargassum are also referred to this group.

Autotrophic (able to photosynthesize) phytoplankton and those bacteria that can feed chemo/photo-autotrophically are the primary producers of the organic matter in the Ocean. All other groups are consumers, utilizing organic matter already created by the producers.

Zooplankton includes both animals living in the water column throughout their life cycles and those dwelling in the water column only for a certain part of their life cycles (mainly larval stages) and then living on the bottom.

In order to be suspended in water, i.e. to be neutrally buoyant, planktonic animals have numerous adaptations. Animals have light skeletons and oil bubbles, which both lead to decrease of relative weight, and the oil serves as an energy store. Unicellular algae can regulate the ionic composition of their plasma and change weight by changing the proportion of heavy ions. Both plants and animas may have various appendages, simple and serrate setae, etc., or form slime constructions which, like parachutes, retard sinking. All these adaptations allow organisms to occupy favourable depths with minimal waste of energy.

The actively swimming pelagic animas that can cope with strong currents and migrate over long distances are fishes (from the largest sharks to shoals of anchovy), squids and cetaceans; these comprise the nekton. The largest nektonic animals can migrate horizontally over distances of hundreds and even thousands of km. For example, Pacific albacore (a species of tuna) migrate annually from Japanese to American shores. Small fishes and larger shrimps 5-10 cm long are often called both micronekton or macroplankton, indicating that the boundary between plankton and nekton is somewhat conditional and not well defined.

Animals living on the seafloor or inside the bottom sediments are called benthos. Those living inside the sediments, like worms, most bivalve mollusks, sea cucumbers, etc., are considered as infauna. Those living on the surface of bottom sediments, like starfishes, most gastropod mollusks, corals, etc., are called epifauna. Attached epifauna that filters suspended organic matter is called sessile benthos, while those animals moving on the bottom freely and consuming dead or live organic matter are vagile benthos.

Some benthic animals (crustaceans, polychaetes, and even sea cucumbers) are able to swim in the water column. At the same time, some planktonic and nektonic animals are trophically related to the bottom populations or feed on the sunken corpses of large pelagic animals (like rat-tail fishes and lysianassid amphipods). All theses animals inhabit the near-bottom layer of the ocean some tens of meters thick, but may sometimes swim in the water column at hundreds and even thousands of meters above the sea floor. This ecological group is very significant in the trophic structure of the Ocean and is called benthopelagic. On the continental shelf, this group occupies the whole water column and is especially important at night when many animals (so called "demersal plankton") ascend from the bottom.

The main part of the bottom population is consumers, living on the sunken organic matter created in the surface ocean layer (the euphotic zone). However, at shallow shelf sites, where there enough light for photosynthesis, many multi-cellular macrophytous algae occur (e.g. *Fucus*, *Laminaria*, Rhodophyta, etc.) and the biomass of theses algae can reach hundreds of kg/m^2. In contrast to the land plants, macrophytous algae have no roots. They just get "anchored" on/in the bottom and obtain all their necessary nutrients from the surrounding water.

The other source of primary organic matter in the benthic ecosystem is the chemo-lithotrophic bacteria that use the chemical energy of hydrogen sulphide (H_2S) and methane (CH_4). These bacteria are part of the ecosystems associated with hydrothermal fields in the rift oceanic zones (at depths of less that 1000 to 4000 m) and in the cold seepage areas near the bases of the continental slopes in the zones of subduction (e.g. convergence and deepening) of the lithosphere plates. According to modern estimation, less than 1% of the total oceanic primary production is attributable to bacterial chemosynthesis. However, as only few percent of the photosynthetic organic matter reaches the ocean depths (2000 to 3000 m), both sources of organic matter are equally important for the deep-sea consumers.

1.3. Biodiversity

Biodiversity of the Oceans is extremely high and, if insects (about 1.5 million species) are excluded, the number of marine species exceeds that of land species. However, some groups such as mammals, birds, spiders, and oligochaetes, are more diverse on land. A few land animals, e.g. amphibians, are completely absent from the sea, and all birds breed on land, even if some such as penguins, petrels, albatrosses, etc. feed exclusively in or on the sea on marine animals. Among insects, only halobathid bugs run on the ocean surface and larvae of some chironomid gnats live in the coastal waters of coral reefs.

Faunal biodiversity within different taxonomic groups (phyla, classes) significantly varies. The most abundant marine groups are crustaceans (>20 000 species), fishes (>12 000 species), mollusks (>10 000 species), polychaetes (>7000 species), echinoderms (6600 species), rhizopods (6500 species), bryozoans (4000 species), coral polyps (3000 species), sponges (2800 species), and sea squirts (2000 species). Along with these abundant groups, several minor taxa live in the ocean, of which the most important are chaetognaths and pogonophorans (150 species each), ctenophores (80 species), salps (25 species), priapulids (15 species), and pyrosomes (10 species). The total number of animal species living in the oceans and seas is impossible to calculate, as many of them, especially those living in the deep sea, remain unknown to science. However, this number is much more than 100 000 species. The biodiversity of marine plants, both unicellular planktonic and multi-cellular benthic, is much lower.

1.4. Creation of the primary organic matter

All marine animals live on the organic matter created from inorganic compounds in the course of autotrophic synthesis with use of external energy. During this process, organic matter with high potential energy is created from mineral compounds with lower potential energy. This synthesis is called the autotrophic production.

The autotrophic production requires input of external energy. In the sea, the most important component is the solar radiation utilised by the plants. There is some input of photosynthetic bacteria, but this is not very significant. More than 99% of the organic matter in the sea is created by plant photosynthesis. Another type of organic matter synthesis is performed by some bacteria which secure external energy while oxidising simple compounds, mainly hydrogen sulphide (H_2S) and methane (CH_4). The energy obtained is used for creation of organic compounds from carbon dioxide (CO_2) and water (H_2O). This type of synthesis is called chemo-autotrophic or chemo-lithotrophic.

Thus, it is the algae that play the major role in the creation of organic matter. Solar radiation is necessary for photosynthesis and, therefore, this process is possible only within the euphotic layer, where the light intensity is enough for photosynthesis. In fact, the lower border of the euphotic layer is the depth where 0.1 to 1.0% of the surface solar radiation penetrates. Depending upon the turbidity and other water characteristics, the thickness of the euphotic layer ranges from 2-3 m in turbid shore waters to 120-150 m in the transparent tropical halistatic areas (anticyclonic gyres), like the Sargasso Sea.

Along with carbon dioxide (CO_2) and solar energy, such elements as nitrogen, phosphorus, iron, etc. are also necessary for creation of organic matter; these are called nutrients. Their shortage in water may be a limiting factor as significant as lack of solar radiation. In the Ocean, the productivity of the upper layer (30 to 150 m) is largely determined by the extent of vertical mixing, providing transport of nutrients from deeper waters where their stock is practically unlimited and exceeds their annual loss by several orders of magnitude. In the water column the primary producers are the phytoplankton cells. In different oceanic areas and at different depths of the euphotic zone, phytoplankton composition and photosynthesis rates vary. Very near the ocean surface photosynthesis is suppressed by the high light intensity, while in the deepest layers of the euphotic zone it is the lack of radiation that causes the reduction of photosynthesis. It is important that photosynthetic algae are not be transported to the deep dark layers during the turbulent mixing. High plankton biomasses are possible in those areas and during those periods when stratification of water layers is prominent (provided light and nutrients are in sufficient abundance).

In shallow coastal waters where light penetrates down to the bottom, multicellular macrophytous algae are developed. Sometimes they are attached to the bottom at greater depths and only their photosynthetic parts grow in the photosynthetic zone as, for example, in the "kelp forests" off California and Oregon. These algae may be as long as tens of meters. The contribution of multicellular algae to total primary production may be significant in shallow seas and near-shore areas. However, for the Ocean in general, it is tiny planktonic algae that dominate in the creation of new organic matter, while the share of the near-shore macrophytous plants is only 5% of the total production.
Through use of radioactive methods, remote sensing and data on ocean colour, it became possible to obtain global estimations of primary phytoplankton production and its temporal and regional variability. The value of the *per annum* primary production (in carbon units) is now estimated as 70-100 x 10^9 t C/year. The geographic breakdown is 43% in the Pacific, 31% in the Atlantic, and 26% in the Indian Ocean. The comparative production rates (per unit area) are higher in the Atlantic Ocean (340 g C/m^2/year) and decrease in the Indian Ocean (330 g C/m^2/year) and in the Pacific (270 g C/m^2/year).

Seasonal changes in the primary production are mainly related to the seasonal cycle of phytoplankton development. In the most productive temperate waters, primary production increases in spring and summer, and decreases in autumn and winter. But in the summer there is an increase in the area of anticyclonic gyres (which are the least productive), to double their area in winter. The Ocean "breathes" and the main part of the organic matter is created either in temperate (northern 40^o) or tropical areas. The value of the total oceanic primary production is almost independent of the season (24% both in summer and autumn, 27% in winter, 25% in spring). In general, 29% of the total primary production is created in temperate waters, while 71% is created in the less productive but larger tropical areas.

Part of the primary production is dependent on nutrients released by decomposition of organic matter in the euphotic zone. This is so-called ‘recycling production’. A proportion of the dead plant and animal matter sinks along with the products of their metabolic activity to the deep waters and is there mineralized; the nutrients may then be transferred upward back to the euphotic zone and become the base of new primary production. Therefore, it is in those areas with intensive upward water fluxes (seasonal mixing, upwellings, divergences, hydrologic fronts, etc.), that concentration of nutrients rises and primary production is increased. These are the most productive oceanic areas. Average phytoplankton concentration in such highly productive areas reaches 7 g C/m^2, while in poorer (oligotrophic) areas limited in nutrients (like centres of tropical anticyclone gyres like the Sargasso Sea), average phytoplankton concentration is an order of magnitude lower and does not exceed 0.3 to 0.5 g C/m^2.

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Biographical Sketches

Mikhail Vinogradov was born in 1927 in Moscow. He graduated from the Biological Department of Moscow State University (1952) and started work in the P.P. Shirshov Institute of Oceanology as a researcher. From 1967 to 1997 he was Vice Director of the Institute (curator of the Biological Branch), and is now Adviser to the Director. Since 1971 he has been head of the Laboratory of Plankton Research. He is also a Professor of the Biological Department of Moscow State University. In 1955 he supported his Ph.D. thesis, and in 1965 a Doctor of Science thesis. In 1984 he was elected as a corresponding member and in 1990, as a full member of the USSR (now Russian) Academy of Science. In 1988 he was elected as Foreign member of the Polish Academy of Science. He has published about 420 papers including 12 monographs. A number of these were translated abroad - in the USA, Japan, Poland, Israel, and France. He is Chief Editor of the journal "Okeanologya" ("Oceanology"), and a member of the editorial boards of the following journals: in Russia - "Biologya Morya" ("Biology of the Sea"), "Priroda" ("Nature" (Moscow)), "Russian Journal of Aquatic Ecology"; the international ones - "Marine Biology", "Journal of Plankton Research", "Polskie Archiwum Hydrobiologii" ("Polish Archives of Hydrobyology"). His main fields of interest cover the investigations of ecosystems and the functioning of pelagic communities of the oceans and seas, mainly the Black Sea and the Arctic seas.

Alexander L. Vereshchaka was born in 1965 (Khimki, Moscow Region, Russia) and graduated from Secondary School (Khimki) in 1982. From 1982 to 1987 he was a student of Moscow State University (MSU), Department of Invertebrate Zoology. He graduated from the University in 1987. M.Sc. Thesis: “Distribution of zooplankton in the Black Sea”. From 1987 to 1990 he was a postgraduate student in the

Shirshov Institute of Oceanology, Russian Academy of Sciences (SIO RAS). Ph.D. thesis: “Macroplankton (mysids, euphausiids, and pelagic decapods including larvae of the bottom-dwelling species) in the contact zones of seamounts and continental slopes”, supported by SIO in 1990. From 1990 to 1993 he was Researcher in the Global Climate and Ecology Institute, RAS and State Committee for Hydrometeorology. Since then he has been:

1993–1997 – Researcher in the SIO RAS.

1997–2000 – Senior Researcher in SIO RAS.

Since 2000 – Leading Researcher in SIO RAS.

Summary of Scientific Degrees

1987 – Master of Science in Biology, MSU

1990 – Candidate of Sciences (=Ph.D.) in Biology, MSU

1999 – Doctor of Sciences in Biology, SIO RAS

Invited Positions

May–June 1990, November 1992 to January 1993, February–April 1995, May–July 1996, and February–April 2002 – Researcher at the Zoological Museum, University of Copenhagen, Copenhagen, Denmark.

February–June 1999, December 2000–February 2001 – Professor at the Museum National d'Histoire Naturelle, Universite Paris VI, Sorbonne.

Fields of Scientific Interest

- General problems of marine biology
- Plankton ecology
- Community ecology
- Deep-sea biology
- Vertical distribution of plankton
- Hydrothermal biology
- Biology of the near-bottom boundary layer
- Visual methods in deep-sea biology
- Systematics and taxonomy of Crustacea

Scientific Publications

About 50 research papers including those in Deep-Sea Research, Marine Biology, Advances in Marine Biology and six monographic publications plus one edited book.

Languages

Russian, English, French.