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Spatial and Temporal Variation of Plankton Productivity in Marine Habitat

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INTRODUCTION

Spatial variability occurs when a quantity that is measured at different spatial locations exhibits values that differ across the locations. Under pure spatial variation, factors vary across a spatial transect but are constant from one time period to another. Under pure temporal variation, factors vary from one time to another but are constant across space.

Phytoplankton are the free-floating organisms of the sea that are capable of photosynthesizing organic matter as their food i.e., primary producers. These are the autotrophic organisms, as they bear chlorophyll and synthesise organic matter, and hence are the major primary producers in the marine ecosystems. Phytoplanktons are microalgae, which include diatoms, dinoflagellates, blue-green algae, silicoflagellates, etc. Diatoms with their characteristic yellow-brown pigment that masks their green chlorophyll are also called golden algae. They are unicellular and either solitary or chain forming. The cell contents are enclosed in a unique glass (pill box), which is called as frustules and have no visible means of locomotion. The frustule is made of two parts, much like a petridish /petriplate, one valve fitting over another. The upper part (largest part) is called as epitheca and the smaller part is called as the cell wall (frustule) is made of silicon dioxide. The valves or the frustules are highly ornamented with species specific designs, pits and perforations, which make the frustule a lot lighter in weight and also provide a place for materials to move in and out of the cell. Dinoflagellates are unicellular and very abundant next to diatoms. They have characteristics of both plants and animals. Like plants, they prepare their food materials by converting sunlight and nutrients in water into food and however, like animals, many varieties of dinoflagellates eat microscopic particles of organic matter found in the water. Some dinoflagellates even eat each other, the condition of which is known as phagotrophy. They have two whip-like appendages, called flagella, which provide some mobility. They lack an external skeleton of silicon but are impregnated with armored plates of the carbohydrate, cellulose.

Zooplankton are the various free-floating animals, i.e., heterotrophic or primary and secondary consumers. All the animal components of the plankton are called zooplankton. They are heterotrophic in nature as they depend on the already formed organic matters for their source of food. Their food materials include phytoplankton, smaller or microzooplankton and detritus. Zooplankton encompass many different groups of animals that range in size from microscopic crustaceans to jellyfish which measure a few feet across. As many zooplankton can feed on tiny phytoplankton, and are in turn eaten by larger zooplankton, fish, or even whales, zooplankton form an important and intermediate link in the food web between primary producers and the higher trophic levels. E.g., copepods, foraminifera, siphonophores, eggs and larvae of fishes, veliger of molluscs etc.

The environmental factors such as light, temperature and nutrients interact with each other in the marine environment and play a major role to produce the spatial and temporal variations in productivity.

Chlorophyll as an indicator of plankton productivity

Chlorophyll is a green pigment found in almost all plants, algae, and cyanobacteria. It is an extremely important biomolecule, critical in photosynthesis, which is a chemical process that converts carbon dioxide and water into organic compounds, especially sugars, using the energy from sunlight. Chlorophyll a is the most common specific form of chlorophyll, and is present in all oxygenic photosynthetic organisms. In phytoplankton, it constitutes generally about 1 to 2 % of the dry weight. Other accessory pigments like chlorophyll b and c may occur in phytoplankton. The presence or absence of such various pigments is used, among other features, to separate the major algal groups. Concentration of chlorophyll a in seawater, expressed in $\mathrm{mg.m^{-3}}$ or in µg. L-1, is commonly used as an indicator of phytoplankton biomass. Phytoplankton, which are the main marine primary producer, are essential for marine ecosystems. They are the foundation of the marine food chain, feeding everything from microscopic, animal-like zooplankton to multi tonne whales. Via their role on the carbon cycle, phytoplankton productivity is also one of the main forces regulating our planetary climate. Indeed, through photosynthesis, phytoplankton consume carbon dioxide on a scale equivalent to forests and other land plants. They thus decrease the oceanic carbon dioxide concentration which will in turn regulates the atmospheric carbon dioxide level. Finally, still through the reaction of photosynthesis, phytoplankton release high quantity of oxygen, essential for the life in the water. Through ocean-atmosphere exchanges, they are also the source of most oxygen in earth’s atmosphere. All those actions make phytoplankton of incalculable importance for all organisms living on Earth, either from marine or terrestrial ecosystems. As chlorophyll a concentration is an indicator of phytoplankton abundance and biomass, it is an excellent indicator of trophic status of any water body and helps to prevent from eutrophication risks. It is also commonly used to measure water quality and thus to determine the level of pollution of water. High levels often indicate poor water quality and low levels often suggest good conditions. However, elevated chlorophyll concentrations are not necessarily a bad thing. It is the long-term persistence of elevated levels that is a problem.

Chlorophyll is popular because it is relatively easy to measure compared to algal biomass and does not suffer from the interferences (detritus and non-algal particulates) found in the other variables.

Fluctuation of phytoplankton biomass (expressed as chlorophyll a concentration) is under the influence of several biotic and abiotic factors, including light and temperature regime, natural and anthropogenic nutrient sources, predation, and water residence time. All of these features undertake temporal variations, which occur on the short (from 1 day to 1 week), mid (seasonal) and long term (inter-annual), inducing temporal variations of phytoplankton abundance and activity and implying that any description of those variations.

The spatio-temporal variation of plankton productivity of different marine habitats are given below:

TEMPERATE SEAS

In the temperate zone seas, the amount of light varies seasonally. As a result, the amount of solar energy entering the water varies, which alters the temperature in the upper water layers. The thermal structure of the water column, therefore, changes seasonally. In the summer months, the sun is high, days are long, and the upper layers heat up and become less dense than underlying layers. In other words, the water column is thermally stratified and no mixing occurs. In the fall, the amount of solar energy entering the water column decreases, days become shorter, upper, layers cool, and thermal stratification decreases. Finally, a point is reached where the temperature of the surface layers has been reduced to such an extent that the density of the layer is little different from that of the underlying mass. At this point, mixing can occur when ever sufficient wind is available.

In winter, usually the storm season in the temperature zone, the sun is lowest on the horizon, solar energy input to the water is at a minimum, thermal stratification is at a minimum or absent, and mixing occurs. With the onset of spring, the days become longer, the solar energy increases, the upper layers begin to rise in temperature, and the system moves toward reestablishment of thermal stratification. In contrast to the tropics, all the major factors that affect productivity changes seasonally in temperate seas. This is reflected in the change in production over the year, with a major peak in spring, a lesser peak in the fall, and low productivity in winter and summer. It may be explained as follows: The low winter productivity is the result of low light levels due to the low position of the sun on the horizon and because the winter storms mix the isothermal water column and carry plant cells below the critical depth. In the spring, the increased light and solar energy increase the temperature of the upper layers. With increasing temperature come increasing differences in density between upper and lower layers. Under such conditions the wind cannot mix the water to as great a depth as in winter; at some point, algal cells are no longer carried below the critical depth. Since nutrients in upper layers have been replenished during the winter mixing, conditions are good for phytoplankton growth, and we observe the spring bloom. As spring passes into summer, the water column becomes more thermally stratified, mixing with lower levels ceases, and light conditions reach optimal levels. Because mixing ceases due to stratification, nutrient replenishment ceases and production falls, even though light levels are optimal. With the advent of fall, the thermal stratification begins to break up and nutrients and returned to upper levels. If, in the fall, the mixing alternates with calm weather such that the phytoplanktons spend more of their time in the upper layers and are not carried below the critical depth, a small bloom will occur because of the increased nutrients. This bloom declines in late fall, due to decreasing light and increased mixing. In the winter, low light levels and deep mixing of the water column keep productivity low. There are differences in the seasonal cycle curves between the temperate North Atlantic and North Pacific. These differences are the result of somewhat different hydrographic conditions, coupled with different nutrient concentrations and availability.

TROPICAL SEAS

In the tropical seas, the upper waters are well lighted throughout the year because the sun does not show marked changes in height above the horizon. Light conditions are, therefore, optimal for phytoplankton production. At the same time, the continual input of energy from the sun maintains the surface layers of water at temperatures much higher than those in deeper waters. This means there is a great difference in density between surface and deep waters; hence, mixing does not occur. This thermal stratification extends throughout the year. In the tropical seas, the light conditions are optimal for high productivity. Because the sun's energy creates a thermal stratification in the water column that prevents mixing and the upward transport of nutrients, however, the productivity is low but constant all year. Tropical seas are very clear and have the deepest compensation depths, but they are that way because there are few phytoplankton in the water column due to the low nutrient content.

POLAR SEAS

In Polar areas, productivity is restricted to a single short period in the polar summer, usually July or August in the Arctic. At this time, the snow cover on the ice has disappeared, allowing sufficient light to enter the water through the ice to permit phytoplankton growth. In areas outside of the permanent ice pack, breakup of the ice at this time opens the leads, allowing sufficient light to enter the water and permitting phytoplankton growth. Following this single burst of growth, the production quickly declines. Nutrients are not limiting and the water column is never strongly stratified. The reason for the lack of production at other times is due primarily to lack of light. Light intensity is insufficient for a fall bloom, and during the long winter, light is either absent or prevented from reaching the water column by a layer of snow over the ice pack.

PRODUCTIVITY IN INSHORE AND COASTAL WATERS

The latitudinal variations in phytoplankton productivity apply to open ocean areas away from the influence of landmasses. The situation in the water masses adjacent to land is somewhat different. There are several factors that contribute to this difference. First, inshore waters tend to receive a considerable input of the critical nutrients, $PO_4{}^{-3}$ and $No_3{}^{-1}$ due to runoff from the adjacent land where, the nutrients are far more abundant. Because of this input, inshore waters usually do not show nutrient depletion. A second factor contributing to the difference is the water depth. Most inshore waters are shallower than the critical depth; thus, the phytoplankton cannot be carried below this depth in any kind of weather. Given sufficient light, production can occur at any time, even in the winter. A third factor is that shallow inshore waters rarely have a persistent thermocline; hence, no nutrients are locked up in bottom waters. A final influencing factor is the presence of large amounts of terrigenous debris in the water, which may act to restrict depth of the photic zone and counteract the high nutrient concentration and shallow depth. Interaction of these factors on a latitudinal basis produces changes, both in the cycle of productivity and in the total production when compared to offshore areas. In temperate regions, instead of a bimodal production cycle, as seen offshore, production remains high all through the summer. Nutrients are not limiting due to runoff from land and lack of a permanent thermocline. Yearly average production in inshore temperate waters is higher than in offshore waters due to the greater nutrient concentrations and lack of critical depth problems. The production is not even higher inshore probably is due to the presence of large amounts of light-absorbing debris in shallow water, and the fact that in offshore water, production can occur to a greater depth. In other words, in shallow waters production is limited to the upper 5-10 m, whereas offshore it may go as deep as 50 m. In tropical waters, the difference between inshore and offshore waters is particularly dramatic. Inshore tropical waters have a productivity as much as ten times that of offshore waters. This must be attributed in large par to the increased nutrient concentration inshore compared with offshore areas. Whereas we may have higher productivity in inshore or neritic waters, we also have greater variability over time and space due to local geography, river and stream discharge, storms, and tides. As a result, it is more difficult to predict the yearly productivity.

DISTRIBUTION OF PLANKTONS

General geographical distribution of plankton

It has been claimed by some of the Oceanographers that the polar seas support abundant plankton than do the tropical ones.

Horizontal distribution of plankton

Wind is one of the most common causes of irregularity in horizontal distribution of plankton. Other important factors which are responsible for horizontal distribution of the plankton are : Inflowing streams, Irregularity of shore line, Depth of water, Flowage areas, Water current, salinity, nutrients etc. .

Vertical Distribution:

The upper most waters are the home of the chlorophyll bearing plankton and perhaps the light plays an important role indicates the distribution of phytoplankton. The blue green and green phytoplankton (Myxophyceae and Chlorophyceae) concentration is maximum than diatoms and this has been thought to be due to the heavier weight. Maximum populations of chlorophyll bearing phytoplankton are at some level below the surface waters. The blue green algae as a group tend to concentrate towards the surface.

CONCLUSION:

In the last 100 years, intensive human activities along the coastlines have dramatically altered marine environments through urbanization, sand erosion, waste management, uncontrolled sewage and urban run-off, all of which have increased the flux of growth-limiting nutrients from the landscape to receiving waters. A strong positive response from marine phytoplankton biomass to nutrient enrichment is accepted although it is very important to take into account the system-specific features of an area to distinguish changes in the ecosystem resulting from natural seasonal and inter-annual dynamics. Because of the high variation in natural conditions and the interaction of multiple factors which influence eutrophication, ecosystem responses to nutrient enrichment are frequently non-linear. From a biological point of view, the response to nutrient enrichment depends on a variety of mitigating factors, such as basin morphology and substrate characteristics, tidal energy, stratification, temperature, light availability, UV radiation biological community structure, nutrients ratio and seed populations.

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