CMFRI

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Impact of Climate Change on Indian Marine Fisheries

Lecture Notes

Part 1

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CLIMATE CHANGE AND MARINE ECOSYSTEMS

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Introduction

In a natural environment, all organisms depend upon plants, which use light energy in the process of photosynthesis to convert carbon dioxide and water into sugars and other essential compounds, and accomplish the manufacture of organic molecules. Plants are the most familiar of these organisms, but many bacteria can also manufacture organic substances with the aid of light or chemical energy. Plants are consumed by herbivores, and carnivores in turn, consume the herbivores.

Primary productivity is the amount of living material produced in photosynthesis, per unit area per unit time. In contrast, secondary productivity refers to the production of plant consumers, or herbivores, per unit area per unit time. The productivity of carnivores, or consumers of herbivores, is tertiary productivity. In general, primary production is greater than secondary production, which in turn is greater than tertiary production.

The levels of biological organization of interest in fisheries ecology are: organism-population-community-ecosystem. This involves a series of processes from individuals to ecosystems.

Ecosystem

An ecosystem is a group of interdependent biological communities in a geographic area, capable of living nearly independently of other ecosystems. Ecosystems are parts of nature where living organisms interact among themselves and with their physical environment. An ecosystem includes biological community integrated with its physical environment. Ecosystems can be recognised as self-regulating and self-sustaining units. Human activities such as fishing and dredging may modify and affect the marine ecosystems.

An ecosystem has two basic components: abiotic and biotic. Abiotic components comprise of inorganic materials such as carbon, nitrogen, oxygen, CO_2 etc, and dead organic matter contain protein, carbohydrates, lipids, etc. The climatic parameters like solar radiation and temperature determine the abiotic conditions within which the organisms carryout life functions. Biotic components include producers, consumers and decomposers.

Biotic and abiotic components are physically organized to provide a characteristic structure of the ecosystem. Important structural features are species composition and stratification. Some ecosystems (e.g., the coral reef ecosystems) show very high species richness, whereas deep-sea ecosystem shows fewer species and extensive bare patches of water.

Within the ecosystem, nutrients recycle between organisms and the environment. Some of the species (e.g. plants) manufacture organic molecules using only solar energy and inorganic chemical sources and the system can continue independently of other systems. Under this definition, a large lake and its immediate drainage comprise an ecosystem, because the organism in the lake can survive indefinitely. A coral reef and its immediate surrounding water also qualify as an ecosystem, because no import is necessary to sustain the system. In reality, all ecosystems exchange nutrients with other ecosystems. It is crucial, therefore to determine the boundaries of an ecosystem and the places where losses and gains may occur.

Another way to depict the ecosystem structure is through food relationships.

Ecosystems possess a natural tendency to persist. This is made possible by a variety of functions (activities undertaken to ensure persistence) performed by the structural components. For instance, phytoplankton function as sites of food production; herbivores like the oil sardine perform the function of utilizing part of phytoplankton, and in turn, serve as food for carnivores. Decomposers carryout the function of complex organic materials into simpler inorganic products, which can be used by the producers.

A food chain is a set of connected feeding levels of primary, secondary and tertiary sources of productivity. An example of a simple food chain is:

Seaweed → gastropod → fish → shore bird

In more complicated systems, a simple chain cannot be constructed, and a more complex food web is a better description. A food chain is a linear sequence that reveals which organisms consume which other organisms in an environment. A food web is a more complicated diagram of feeding interactions that shows the overall pattern of feeding among organisms.

Each organism in the above food chain (seaweed, gastropod, fish and bird) represents a trophic (food) level.

The energy flows in one way *i.e.,* from producers to herbivores to carnivores. It cannot be transferred in the reverse direction.

Not all the production from one trophic level is transferred perfectly to the next. To estimate the potential production at the top of a food chain such as fish production, the losses at each trophic level should be determined. Losses result from the following two factors:

(i) Unconsumed: Some proportion of a given trophic level evades consumption through escape, unpalatability or unavailability. Phytoplankton with large spines or toxins are avoided by zooplankton. Phytoplankton cell size may be too small, or too large, to permit ingestion.

(ii) Inefficient conversion: Some portion of the food that is ingested is not converted for growth.

A budget for consumed food can be constructed as follows:

$C = E + R + G$

Where C is the amount consumed, E is the amount egested as faeces and nitrogenous waste, R is the amount spent in respiration, and G is the amount used in growth. G can be partitioned between somatic growth and reproduction. This budget is usually constructed in terms of energy units, i.e., calories or joules.

The energy lost in respiration is not available to the next trophic level. The respiration cost increases sharply along successive trophic levels. On an average, respiration of producers consumes about 20% of its gross productivity. Herbivores consume about 30% of assimilated energy in respiration. The proportion of assimilated energy consumed in respiration rises to about 60% in carnivores. Because of this tremendous loss of energy at successive higher trophic levels, the residual energy is decreased to such an extent that no further trophic level can be supported.

Animal that has no immediate predators also contribute nutrients to the food web. Marine mammals and turtles, while not specifically targeted for consumption, do produce waste. The waste may be either excretions from digestive processes or dead tissue. Decomposers eventually break it down, *i.e*., primarily bacteria, in a process that releases nutrients those plants can use to start the whole cycle again.

Organisms higher up the food web tend to be larger in size and fewer in number than those at lower levels. This is partly a function of the many trophic steps required to meet advanced energy needs. Because the efficiency rate at each trophic level is only about 10%, each succeeding level supports a smaller total biomass to compensate for the 90% loss of food value.

The incompleteness of transfer up a food chain can be estimated in terms of ecotrophic efficiency, EE, defined as the amount of energy extracted from a trophic level divided by the amount of energy supplied to that trophic level. EE is often in the range of 10%. However, high latitude planktonic systems may have higher EE.

Ecosystem impacts of fisheries

Fish populations do not live by themselves. Rather, they are embedded in ecosystems where they perform their roles as consumers and prey of other organisms, including larger fishes. For describing the ecosystem impacts of fisheries, it is necessary to concentrate on the impacts fisheries have on food webs, *i.e*., on the net work of flows of matter (= biomass), which in ecosystems, links the plants with herbivores, and the latter with their predators. These networks of flows are affected directly by fishing, which removes predatory fish, or competes with them for their preys, in either case affecting the web within which predators and preys are embedded.

The plants have a definitional trophic level of 1, as does dead organic matter (detritus), while exclusive plant or detritus feeders (herbivores or detritivores) have a trophic level of 2. Carnivores feeding exclusively on herbivores and/or deritivores have a trophic level of 3, and so on. Carnivores do not necessarily have trophic levels of exactly 3 or 4, but are more likely to have intermediate values, reflective of the mix of preys they consume. For example, a pelagic shark that should have a trophic level of 5.0 because it feeds on small pelagics such as whitebaits with a trophic level of 3.0 will end up having a trophic level of 4.0 if it feeds, equally, on a low level carnivore or herbivore like the sardines with a trophic level of 2.0-2.5.

Because of this effect of mixed diets, top predators in marine ecosystem rarely have trophic levels in excess of 5. Such high values occur only in killer whales, which, by feeding exclusively on marine mammals (which prey on piscivorous fish), can reach trophic levels much higher than those reached by fish. While some fish reach trophic levels > 4.0, the overwhelming bulk of them have trophic levels between 3 and 4.

Ecosystem maturity

The stability of the ecosystem is high, if the energy flow of the network is high. The complex trophic organization of a community is more stable than a simple one. A more diverse ecosystem has the potential of becoming more complex and possessing more choice than a less diverse one. An ecosystem attains maturity after several ecological successions, and hence development and maturity of an ecosystem stand in opposition to each other. A mature ecosystem has the capacity to withstand perturbations caused by human beings or nature more than an immature ecosystem.

The question is whether ecology can help in managing fisheries. The two basic answers could be:

(i) Ecology may help in finding out what is the carrying capacity of the ecosystem. This carrying capacity, measured as the sum of all the possible fluxes in the ecosystem, represents the available energy from which maximum can be diverted as fish catch. It is also possible to arrive at a limit of what one can get from an ecosystem.

(ii) Ecology may help by characterizing the space and time where the valuable species should be protected. However protection should not be extended only to a few species. Also, species that have an ecological impact on the valuable species should find protection in space and time, and ecology can elucidate what those species are.

(iii) Recently, ecology and ecosystem analysis are used to interpret the effects of natural and human influence on fisheries, and this analysis is helpful for recommending ecosystem-based fisheries management options.

Impact of climate change

Since life began on earth, changes in the global climate have affected the distribution of organisms as well as their interactions. However, human-induced increases in atmospheric concentrations of greenhouse gases are expected to cause much more rapid changes in the earth's climate. The immense area and the modest extent of our knowledge of the open ocean hamper predictions of how ocean systems will respond to climate change. The predicted changes may have a significant effect on coastal ecosystems, especially estuaries and coral reefs, which are relatively shallow and currently under stress because of human population growth and coastal developments.

Significant environmental factors that affect the structure and function of estuarine and marine systems that are expected to be part of global climate change include temperature, sea-level rise, the availability of water and associated nutrients from precipitation and runoff from land, wind patterns, and storminess. Temperature, in particular, influences organism biology, affects dissolved oxygen concentrations in water, and plays a direct role in sea-level rise and in major patterns of coastal and oceanic circulation. Temperature can influence changes in species interactions (e.g., predator-prey, parasite-host, competition for resources). Changes in distribution patterns would change the mix of predators, prey, parasites, and competitors in an ecosystem that could alter the functions of the ecosystem and the productivity of selected fisheries. Predation pressure in marine ecosystems generally increases from the poles to the tropics. So warming due to climate change could cause an ecological shift to increased predation if it led to greater diversity and numbers among predators. Higher temperatures would be lethal to some species at the southern end of their range and would allow others to expand the northern end of their range if they were sufficiently mobile.

The various linkages among species and feeding groups may provide resiliency so that the loss of a few species may not unravel the web. However, there may be a key species or group of species whose loss would be detrimental to the web's integrity, but our knowledge about such matters is limited for most marine food webs. We can expect that some ecosystems may shift abruptly. A key species does not have to be eliminated from a habitat for effecting resultant changes in its ecosystem. For example, the eastern oyster, a filter feeder that pumps water over its gills to trap phytoplankton, was once a significant bottom dwelling component of the Chesapeake Bay ecosystem. For many reasons, their abundances today are about 1 percent of what they were a century ago. As a result, the oyster's ability to filter the bay's water has greatly diminished so that the Chesapeake Bay is no longer a bottom-dominated system. Instead, it is a turbid pelagic system dominated by floating phytoplankton and their zooplankton grazers, and by jellyfish that feed on the zooplankton. The introduction of a new species into an ecosystem can have an influence as important as the loss or decline of a key species such as the oyster. For example, a filter feeding clam from Asia has invaded San Francisco Bay. Its introduction and spread has been followed by changes in local food webs so that sections of the bay harboring these clams are now bottom-dominated systems. The depleted abundances of oysters and the introduction of the Asian clam have had major effects on their ecosystems. Climate change might have similar effects in ways we are not yet able to predict if key species are affected positively or negatively or if invasions of an exotic species are enhanced.

Other Perspectives on Climate Change

There is evidence that marine organisms and ecosystems are resilient to environmental change. The biological components of marine systems are tightly coupled to physical factors, allowing them to respond quickly to rapid environmental change and thus rendering them ecologically adaptable. Some species also have wide genetic variability throughout their range, which may allow for adaptation to climate change.

There are at least two schools of thought among physiologists and ecologists who have considered possible effects of climate warming on the survival of marine animals. Some believe that marine systems experience fewer extinctions of species compared to terrestrial systems because large numbers of marine species have wide geographic temperature ranges as well as greater capacity to migrate to new habitats through their larvae that drift in the water column. Others counter that not all marine species have drifting larvae, and that many larvae are short-lived or remain relatively close to the parental population before becoming juveniles.

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