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Impact of Climate Change on Indian Marine Fisheries

Lecture Notes

Part 1

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CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

CLIMATE CHANGE IMPACTS ON FISHERIES AND AQUACULTURE: A GLOBAL PERSPECTIVE

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Introduction

It has been recognized that climate change will have economic consequences, both benign and disadvantageous. This is particularly true of activities such as agriculture that are directly and critically affected by the weather. The fisheries are even more dependent than agriculture on climatic conditions. While agriculture does up to a point compensate for the shortcomings of nature (through irrigation and fertilization), the fisheries, which essentially are an advanced form of hunting, are totally dependent on what nature will or will not provide.

The effects of climate change on fisheries are likely, therefore, to be more severe than on agriculture. One reason could be that the effects of global warming on fish stocks and their migrations are extremely difficult to predict. There are two main uncertainties in the causal chain from global warming to the fisheries. First, the impact on ocean temperature and currents is uncertain, not just in magnitude but possibly also with respect to direction. Second, even if we knew the change in temperature and ocean currents, we would not necessarily know the effect on abundance and migrations of fish stocks. Nevertheless, it appears that little research has been done on the possible consequences of climate change for fisheries.

Most fish species have a fairly narrow range of optimum temperatures related to both their basic metabolism and the availability of food organisms that have their own optimum temperature ranges. Depending on the species, the area it occupies may expand, shrink, or be relocated with changes in ocean conditions.

Marine ecosystems are not in a steady state, but instead are in a constant state of change that varies on many spatial and temporal scales. Fish populations respond to this variability in different ways. For example, during short-term weather changes such as storms, fish may take refuge from rough conditions through minor changes in distribution. Inter-annual changes in the ocean environment, on the other hand, may result in changes in the distribution patterns of migratory fishes and affect reproduction and recruitment in other species. Moreover, decadal and longer-scale variations may have other impacts, including cyclic changes in the production level of marine ecosystems in ways that may favor one species or group over another (Table 1).

Long-term records of the abundance for most species are limited to historical commercial and recreational landings. These records are often influenced by economic factors such as the relative price paid for different types of fish, and changes in fishing methods or fishing effort. These non-climatic factors often obscure climate-related trends in fish abundance. Most studies of variations in ocean climate and their relationships with fish abundance have been on inter-year time scales.

Changes in fish distribution and abundance

For fishes, climate change may strongly influence distribution and abundance through changes in growth, survival, reproduction, or responses to changes at other trophic levels. Changing seawater temperature and current flows will likely bring increases, decreases and shifts in the distribution of marine fish stocks, with some areas benefiting while others lose. These changes may have impacts on the nature and value of commercial fisheries. Species-specific responses are likely to vary according to rates of population turnover. Fish species with more rapid turnover of generations may show the most rapid demographic responses to temperature changes, resulting in stronger distributional responses to warming.

Table 1: Climate change and its effect on marine fisheries and aquaculture

Drivers	Effects	Implications
Change in sea surface temperature	Algal blooms increase, less dissolved oxygen, parasites increase, invasion of predators, longer growing seasons, shift in location and size, damage to coral reefs.	Infestation of diseases, speciescompositionchanges, increased production, migration, loss of species, recruitment decreases.
Sea level rise	Loss of land, salt-water infusion, changes to estuary, loss of coastal ecosystem and mangroves.	Loss of fresh water species, area reduction for aquaculture, fresh water availability decrease, species shift/composition, distribution changes, reduced recruitment and stock.
Increase in frequency of storms	Turbulent water, salinity changes	Loss of stock, catch decreases, risk to fishers, cost of maintainance increase, damages to vessels, nets etc.
ElNino-Southern oscillation	Location and timing of ocean current changes, upwelling alters food supply, coral bleaching.	Productivity decrease.
Drought	Salinity changes	Loss of stock, fisher folk migration

North Sea

The North Sea demersal fish assemblage composed of more than 90 species with varied biogeographical origins and distribution patterns. No species range was entirely confined to the North Sea. The North Sea waters have warmed by an average of 0.6°C in 40 years between 1962 and 2001. Water temperatures become colder with increasing latitude in the southern North Sea, but become slightly warmer with increasing latitudes in the north. This temperature pattern explains the movement of the Norway pout (*Trisopterus esmarkii*). Its distribution was centered in the northern North Sea, and its southern movement brought it into cooler waters. Most species that showed climate-related latitudinal changes also shifted in depth, because the North Sea depths are positively correlated with latitude. The cuckoo ray (*Leucoraja naeus*), moved deeper with warming but did not change latitude, suggesting that they may respond to climatic variation through local movements into pockets of deeper waters. The boundaries of fishes also moved significantly with warming. Boundaries moved over distances ranging from 119 to 816 km. In the case of bib (*Trisopterus luscus*), the northern boundary shifted by 342 km from 1978 to 2001. Shifting species have faster life histories than do non-shifting species, with significantly smaller body sizes, faster maturation, and smaller sizes at maturity.

There is strong evidence that the catches of cod in the North Sea are influenced by variations in temperature, with lower temperatures leading to increased catches and vice versa. This is presumably associated with variations in the stock, with low temperatures being favorable for the stock. In contrast, the recruitment of Northeast Arctic cod was found to respond favorably to rises in temperature in the Norwegian Sea. The catches from this stock also respond favorably to rises in temperature, with a longer time lag. This supports the notion that rising temperatures in the Norwegian Sea and the Barents Sea would improve the productivity of this stock. Little or no evidence was found, however, for the hypothesis that higher temperatures would drive the cod further north and east.

There is some indication that the catches of mackerel in the Norwegian Sea increase with rising temperature in that area, but the correlation is not statistically significant. The sharp peak of the mackerel fishery in the North Sea in the late 1960s was brought about by technology. There is, however, a significant and positive correlation between temperature and catches of mackerel in the North Sea after the stock recovered in the 1970s. For anchovies in the North Sea, no positive correlation between temperature and catches is apparent, while for sardines there is a significant correlation.

Overall, the conclusion is that in certain cases the past changes in temperature and fish catches are consistent with the expectations that currently are held by many people as to what might be the consequences of warming of the North Sea and the Northeast Atlantic on fish catches. For other stocks there is little or no support from changes in the past for these expectations. That does not prove they are wrong; the temperature may have to rise beyond a certain threshold value to have an effect on stock growth and distribution. Furthermore, catch fluctuations in the past for reasons that have nothing to do with temperature changes may mask an underlying relationship between the two. *Northwest Atlantic*

There are large quantities of zooplankton in the form of copepods and krill and more than 25 commercial stocks of fish and shellfish in the northwest Atlantic. Capelin, an important prey fish of cod, spend most of their time in the colder waters north of Iceland, returning to the warmer waters to spawn. One major result of these phenomena was that cod spawned in large numbers in the north and east of Iceland, as well as in the more traditional south and west. This is an example of fish expanding (not shifting) their range when the ocean water warms. A second major result was that there was a migration of cod larvae to Greenland, which matured and led to a spawning population and an active cod fishery there. With the cooling trend of the late 1960s, cod no longer spawned off Greenland, and ultimately the cod larvae migration from Iceland ceased. The Greenland cod fishery also ended.

In the northeastern North Atlantic, including the North Sea, the Nordic Seas and the Barents Sea, the mean temperature is expected to increase by 1–3°C over the next 50 years. Highest temperature changes are expected to occur in the northernmost part of the region. Moreover, the model scenarios predict ice-free summers in the Arctic basin in 50 years. Associated with such a temperature change is also an increased wind-induced flux of warm Atlantic water to the region and changes in stratification of the euphotic zone. Such changes in ocean climate will substantially impact the marine ecosystems of the region. The changes will impact abundance and distributions of fish species as well as abundance and distributions of key plankton species. Generally, a northward shift in distribution of all species is expected, and an increased biomass production of the Arctic and Arcto-boreal regions. In the North Sea, however, the present fish species to decline, but new species will invade from the south. The area will be dominated by pelagic species such as herring and mackerel in the northern part and possibly anchovy and sardine in the southern part. The cod stock in the North Sea will probably remain small, and this could reduce the value of the catch in this area. Total production will probably not change much, but species composition will change.

In the Barents Sea and the Norwegian Sea, both the herring stock and the cod stock will most likely benefit from the warming. The abundances will increase and the distributions will expand, resulting in more availability for the Russian fishing fleet. The presently relatively unimportant Atlantic cod spawning areas along the Finnmark coast will become more important. New species are likely to appear. For example, Atlantic mackerel might be available in the Barents Sea. Capelin will probably move eastwards, and Novaja Semlya might become new spawning areas.

High-latitude fisheries

Many scientists feel the most radical changes will occur in high-latitude regions. For example, the Arctic Climate Impact Assessment Report concludes that the Arctic climate is changing almost twice as fast as the rate of climatic change at lower latitudes. Similarly, the Center for Global Change and Arctic System Research, University of Alaska, states: "The Arctic is characterized by one of the most extreme environments on the planet, with limited sunlight, extreme temperatures, and a short growing season. Sea ice, snow cover, glaciers, tundra, permafrost, boreal forests, and peat lands are all sensitive indicators of change, susceptible to subtle variations in sunlight, surface temperature, ocean heat transport, air and ocean. Global climate models indicate that global warming induced by the greenhouse effect will be most acute in polar regions, most likely resulting in changes in the extent of sea ice, increased thawing of permafrost, and melting of polar ice masses, with profound societal impacts around the globe".

Similarly, and with particular regard for high-latitude fisheries, information contained in the IPCC and NRC reports suggests the following changes in future decades as a result of global warming and corresponding climatic and ocean-ecological change:

1. According to the IPCC the greatest temperature increases over the last 35 years have occurred in the Arctic and sub-Arctic regions. In parts of these regions the warming has been extreme—as much as 3.9–5.6 °C. Projecting this trend two to three decades into the future, such warming may prompt rapid disruption, alteration, or collapse of various marine-ecological systems as they are unable to adapt as fast as the change is taking place.
2. A drop in aggregate fish production, as the foregoing marine ecosystems are not able to adapt as fast as the environmental changes are taking place.
3. Fisheries scientists may be unable to provide credible assessment advice for preventing major fishery collapses as the climate moves farther from its historic baseline. Widespread stock collapses may be the unavoidable result of poorly informed science and management, as well as the disappearance of many fish species in regions where they have long been plentiful.
4. A rise in sea level between 12 and 75 cm above the current level, with persistent coastal flooding in many regions and permanent inundation in others, causing not only radical marine-ecological change, but also requiring costly relocation of shore-side fisheries facilities.
5. An increase in the frequency and intensity of storms in certain coastal regions, causing widespread destruction to property, economic disruption, and loss of human life.

California sardine and Atlantic herring

The changes in ocean climate that have occurred in the not too distant past have in some cases had dramatic effects on abundance and migrations of fish stocks. One such is the disappearance of the California sardine, and another is the collapse of the Atlanto-Scandian herring stocks. To what extent these events were the result of a climate change or overfishing is difficult to judge. Both events occurred and both were potential causes of a collapse, but their simultaneous occurrence may have been necessary for the collapse to take place. There is evidence that the abundance of both of the stocks has varied considerably over time before the modern age of intensive exploitation, so the influence of climate change should not be ignored. Both of these collapses caused tremendous dislocation in the industries affected. The California sardine was one of the world's largest exploited pelagic fish stocks and the basis of a large reduction and canning industry. After the sardine disappeared, fishermen and fish workers had to seek other employment.

Indian Seas

In the Indian Seas, similar trend has been noticed on the distribution of the oil sardine *Sardinella longiceps* and the Indian mackerel *Rastrelliger kanagurta* as a consequence of seawater warming. These small pelagics, which were predominant along the southwest coast of India, have extended (not shifted) their northern boundary up to Gujarat in the northwest coast and West Bengal in the northeast coast. The Indian mackerel is noticed to descend to depths to avoid higher sea surface temperatures. These are a few strategies adopted by fishes to mitigate seawater warming.

Climatic sensitivity of migratory species

Tuna, in general, are fast swimming top predator species whose high metabolic requirements must be supported by ready access to rich food sources. Their migratory patterns are closely governed by ocean processes that create a conjunction between suitable physical habitat (in terms of temperatures and adequate oxygen) and adequate food sources. The tunas are constantly swimming in search of food—in some circumstances needing to consume as much as 15% of their body weight per day. As a result, the areas of tuna concentration are by no means casual, and migration takes place according to hydrological routes: in which each species finds the optimum environment for survival in every stage of its existence. As they are so energy-consuming, they are dependent on ocean processes and features which promote the aggregation of the prey resources which they must find within finite time periods, or die. These are the fronts, thermoclines and productive shoal regions of the ocean. Climate plays a large role in determining short-term, seasonal and multi-year patterns of variability in the location and productivity of these optimal tuna habitat zones.

Tropical tunas, including skipjack (*Katsuwonus pelamis)*, yellowfin (*Thunnus albacares*) and bigeye (*Thunnus obesus*) tend to be fast growing and relatively short lived. Climate variability has demonstrable impacts on the abundance, concentration, location, and catchability of tropical tuna stocks. Climatic variability drives seasonal changes in the location of the most productive fishing grounds. It also leads to changes in abundance and catchability that are not properly understood. There is evidence that operators of modern tuna fleets are actively using the available information on climatic/ oceanographic impacts on tuna stocks to guide their harvesting operations. Furthermore, intensive scientific research efforts are underway seeking to further clarify these relationships, with the goal of improving predictability. For example, a major international collaborative research effort is now being organized as the Climate Impacts on Oceanic Top Predators (CLIOTOP) Project under the auspices of the International Geosphere-Biosphere Programme–Global Ocean Ecosystem Dynamics (IGPB-GLOBEC) Program. The effects of changed fish migrations and distribution caused by climate variability and climate change are likely to be most difficult to deal with for highly migratory species, such as tuna.

Climate change and international agreements

What other problems are likely to emerge as a result of climate change? Since the late 1970s, much of the ocean has been divided into Exclusive Economic Zones where fishing is at the discretion of the country that controls the zone. Many fish stocks migrate between the zones of two or more countries, or into the high seas where no single state has jurisdiction. The management of such shared stocks necessarily involves cooperation between the countries in whose jurisdiction the fish are found. Changing migrations of fish stocks are likely to put existing agreements under stress and perhaps to lead to their total breakdown. We do have one good example of an international sharing treaty on fish that has broken down as a result of changes in fish migrations due to climate change, the sharing between Canada and the United States of salmon returning to their home rivers on the Pacific side of the North American continent. In the late 1970s there occurred what usually is referred to as a regime shift in the Northeast Pacific. The returning salmon began to take a more northerly route, and much of the fish heading for rivers in Canada could be intercepted by Alaska. Similarly, the salmon heading for the Fraser River in Canada began to take a northerly, all-Canadian route, instead of passing in part through US waters. This led to a breakdown of the US–Canadian agreement on sharing the salmon, which was based on a different migratory behavior of the fish.

The California sardine also offers an example of how climate changes might undermine international agreements on fish sharing. During its low phase, the California sardine contracted south and was almost exclusively found in Mexican waters. In its more abundant state it migrates further north, even as far as into Canadian waters. If a sharing agreement on the sardine had existed in the 1950s it would surely have broken down; there would have been little incentive for Mexico to share a fish exclusive to its home waters with the Americans. One could envisage a scenario of climate change where a stock gradually moves out of the waters of one country and into the waters of another, but with an intermediate phase where it is located in the waters of both, and perhaps in varying proportions, because climate change is likely to occur as a trend with variations.

Harmful algal blooms

Harmful algal blooms have caused considerable mortality of fish in Norwegian waters. Especially, farmed fish are vulnerable since they cannot escape, but also wild fish mortality has been observed. In Norwegian waters the most important harmful algae belong to the genera *Gyrodinium*, *Chatonella*, *Chrysochromulina* and *Prymnesium*.

During recent years, blooms of algae from the genus *Chatonella* have been a major concern along the southern coast of Norway. These algae belong to the group *Raphidophyceae*, which includes most of the potential harmful algal species. No toxic substances have been found in *Chatonella* from Norwegian waters, but the algae do produce mucus, which in combination with high concentrations of the algae may block the gills of fish and cause mortality. The first *Chatonella* bloom was observed in Norwegian waters in 1998. It was then the dominating algae along the coast north to the Boknafjord area. Blooms of *Chatonella* have since been observed in 2000 and 2001. In 2001, the bloom caused a loss of 1100 ton of farmed salmon in farms east of Lista.

It is difficult to quantify the effect of climate change on the probability of an increase in harmful algal blooms. In addition to temperature, factors such as stratification and nutrient supply are important for the occurrence of blooms. Therefore, the blooms will to a great extent depend on discharge from the major rivers surrounding Norwegian and adjacent waters, and this will depend on how the land in the catchment area is used. In addition, new algal species may appear, for instance introduced in ballast water and it is impossible to predict the effect of this. However, it is possible to assess the effect of an increased temperature on the growth of the algae, which cause fish mortality. It was found that growth rates of four of the harmful algae increased when a temperature scenario for 2100 (4 °C increase) was used. The main conclusion is that due to climate change the risk of harmful dinoflagellate and Radiophyte blooms in the Dutch coastal zone will increase rather than decrease.

The algae, which until now have caused harmful algal blooms in Norwegian waters have temperatures of optimum growth ranging between 15 and 20 °C. However, differences between strains of the same species from different areas are known to occur. This means that an increased sea-temperature may increase the growth of these potentially harmful species and thereby increase the probability of harmful algal blooms.

Sea level rise and ecosystem vulnerability

Mean sea level is predicted to rise by 10-90 centimeters during this century, with most predictions in the range of 30-50 centimeters. This will damage or destroy many coastal ecosystems such as mangroves and salt marshes, which are essential for maintaining many wild fish stocks, as well as supplying seed to aquaculture. Mangroves and other coastal vegetation defend the shore from storm surges that can damage fishponds and other coastal infrastructure and may become more frequent and intense under climate change. UNEP estimates the annual worth of mangroves at $ 200,000 - $ 900,000 per square kilometer. A number of studies have identified possible adaptation strategies for mangrove systems that include raising awareness of the importance of these areas among local communities and leaders, identifying critical areas, minimizing stress unrelated to climate, maintaining ecosystem connectivity, coastal planning that facilitates retreat inland, developing alternative livelihoods, and restoring coastal ecosystems. Research to develop these strategies and the means to implement them is desperately needed.

Higher sea levels may make groundwater more saline, harming freshwater fisheries, aquaculture and agriculture and limiting industrial and domestic water uses. Increased inland groundwater salinity has been observed in Bangladesh in recent decades. Along with the negative consequences, however, there may be benefits in the form of increased areas suitable for brackishwater culture of high-value species such as shrimps and mud crab. This situation demonstrates the importance of maintaining people’s capacity to recognize and take advantage of opportunities and how aquaculture can play an important role in diversifying livelihoods.

Temperature increase in freshwater bodies

Higher inland water temperatures may reduce the availability of wild fish stocks by harming water quality, worsening dry season mortality, bringing new predators and pathogens, and changing the abundance of food available to fishery species (Table-2). In Lake Tanganyika, which supplies 25-90% of animal protein for the countries that surround it, warmer temperatures reduced the mixing of surface and deep-water layers in the last century, limiting the nutrients available to plankton and thereby cutting, by an estimated 30%, the yield in fish that feed on them. Identifying and promoting aquaculture species and techniques suitable to changing environments and resources will enable aquaculturists to adapt to changes and may reveal new uses for land that has become unsuitable for livelihoods strategies. Also noteworthy is that, in cooler zones in particular, aquaculture may benefit as rising temperatures bring faster growth rates and longer growing seasons.

Table 2: Climate change and its effects on inland fisheries and aquaculture

Drivers	Effects	Implications
Higher inland water temperature	Reduced mixing of water, primary productivity decrease/increase, reduced food supply to fishes, shift in location and size, pathogen abundance	Fish stocks reduce, loss of species, sprout of diseases.
Changes in precipitation quantity	Migrations, recruitment pattern changes, change in movement of surface water, fresh water supply decreases, risk of drought.	Diseases sprout, maintenance cost increases
Drought	Salinity changes, low water quality.	Loss of stock, production cost increases, fisher folk migration.

Changes in precipitation and water availability

Changes in precipitation averages and potential increases in seasonal and annual variability and extremes are likely to be the most significant drivers of change in inland aquaculture and fisheries. Bangladesh relies on fisheries for around 80% of national animal protein intake. In the theoretical scenario of 2-6°C warming, precipitation is forecast to decline in Bangladesh during the dry season and increase during the wet season, expanding flood-prone areas by 23 to 39%. In many African lakes, water level determines stock fluctuations more than any other factor. This is especially true of lakes that periodically go completely dry, such as Mweru Wa Ntipa, Chilwa/Chiutaand Liambezi. In Lake Mweru and LakeTurkana, for example, catch rates decline when the lake level is low. Flexible management is the key to ensuring benefits flow from an unstable and uncertain resource. Reduced annual rainfall, dry season rainfall, and growing season length are likely to have implications for aquaculture and create greater potential for conflict with other agricultural, industrial and domestic users in water-scarce areas. These impacts are likely to be felt most strongly by the small aquaculture farmers, whose typically smaller ponds go dry more quickly and who may suffer from shortened growing seasons, reduced harvests and a narrower choice of species for culture. Aquaculture may also provide solutions in areas of worsening water scarcity. Schemes that integrate pond aquaculture with traditional crops in Malawi have successfully reduced farmers' vulnerability to drought, provided a source of high quality protein to supplement crops, and boosted overall production and profit. In terms of water use efficiency, systems that reuse water from aquaculture compare very favorably with terrestrial crop and livestock production.

Extreme events such as cyclones and their associated storms urges and inland flooding can wreak sudden and severe havoc on fisheries, and particularly on aquaculture, through damage or loss of stock, facilities and infrastructure. Institutional responses such as constructing artificial flood defenses and maintaining natural ones can provide protection. Short culture periods and minimal capital investment in aquaculture help reduce stock loss and its cost. Other considerations for coping strategies in high-risk areas include monitoring and assessing risk and promoting aquaculture species, fish strains, and techniques that maximize production and profit during successful cycles.

Wider implications of the impacts of climate variation on fisheries

Many artisanal fishers are extremely poor and even when they earn more than other rural people, they are often socially and politically marginalized and afford only limited access to healthcare, education and other public services. With little capacity to adapt, the small-scale and migrant fishers are highly vulnerable to losses of natural capital from climate impacts. To cope with climate-driven fluctuations in production may worsen a range of cultural, social, fisheries management and health problems.

The need for further research, adaptive capacity and coping strategies

Information on the likely impacts of climate change for fisheries is very limited. Moreover, the inherent unpredictability of climate change and its mechanisms of impacts on fishery are complex. Efforts should be made to increase the understanding of how and why climate change may affect aquaculture and fisheries. These efforts should emphasize developing strategies by which fisheries, and perhaps more significantly aquaculture, can play a part in our wider adaptation to the challenges of climate change.

One reason why adjusting to climate change might be more difficult now than it was in the past is that the fisheries in many parts of the world have become more regulated. While the need for regulation is not in doubt it often comes at the cost of flexibility, making it more difficult to enter another fishery if one collapses.

Suggested reading

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