CLIMATE CHANGE AND FISHERIES

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Contents

Summary

Climatic changes influence the numbers and distribution of fish populations directly, through physiological and population dynamics responses to abiotic factors, and indirectly through the availability of food, and the presence of competitors and predators. This article considers climate changes occurring at different time scales, including the interannual (between years, includes El Niño-Southern Oscillation), the interdecadal (Pacific decadal oscillation and North Atlantic oscillation), and the multidecadal (such as the 40 to 60 years fluctuations observed in sardines and anchovies from different systems). Even when this article does not discuss the causes and long term trend of the observed global warming during the last decades, a short review on potential impacts on fish resources is provided. Fisheries tend to be highly vulnerable systems, where economic and social impacts depend on the kind of fishery, the biology of the fish resources, the properties of the environment where they live and the cultural, historical, economic, and social reality of humans participating in the activity. Some discussion on potential adaptation strategies at the regional to national level are also considered, particularly on the value of adopting the flexible economy model as the most socially friendly strategy under high uncertainty scenarios (as those related to

climate changes). Today, fisheries management is moving towards ecosystem based management, meaning that one should regard not only the biology of the target population, but also its ecological interactions with other resources and non exploited populations, the interactions between the fisheries and other values from the ecosystem, and of course the fact that concepts like carrying capacity, limiting factors, and ecological controls, are only instantaneous abstractions to study ecosystems, and that there is no fixed level of biomass for any natural population. Consequently, fisheries sciences are rapidly evolving into a dynamic field with strong interactions of a broad spectrum of disciplines.

1. Climate change

Environmental conditions vary at basically every timescale, influencing ecosystems and complicating the capacity to properly manage natural systems. For short time-scales (i.e. daily and seasonal), good memory of changes are easily recorded, and forecasting capabilities have been developed. Furthermore, several natural processes are considered to be tuned to these variations (reproduction, migration, hibernation, etc.), and that knowledge can also be used to improve the benefits obtained from ecosystems. At longer time-scales, understanding and predicting ability is much smaller.

Climate Change is currently defined to the periods during which the factors that determine climate (the average environmental condition) keep increasing or decreasing for an extended number of years. These variations are further classified as interannual (happening between years, such as El Niño and La Niña), decadal to multidecadal (cycles or conditions lasting for a decade or few decades, such as hydrologic and fisheries cycles), or long term (happening in the centuries to millennia time-scales, such as ice ages). When trends last for long and are widespread over much of the Earth, Global Climate Change is acknowledged, often referred to as Global Warming because of the steady increase in global temperature over the past century. There are many complications to understanding and differentiating long term natural variations from human induced climate changes; however, aside of origin, future climate variations will impact natural ecosystems and should be considered when planning our future.

Times of strong climate changes are currently noted, and also of strong social, political, and scientific awareness. Countries are organized through regional, national and international plans and agreements, institutions, and scientific programs (Table 1). If emerging information is effectively incorporated into politics and management, sustainability of natural resources might greatly improve.

Name	Acronym	Web address
Asia-Pacific Network for Global Change Research	APN	www.apn-gcr.org/
Climate Variability and Predictability	CLIVAR	www.clivar.org/
Global Climate Observing System	GCOS	www.wmo.ch/web/gcos/
Global Environmental Change and Human Security	GECHS	www.gechs.org/
Global Ocean Ecosystem Dynamics	GLOBEC	www.globec.org/
Global Ocean Observing System	GOOS	www.ioc-goos.org/
Inter American Institute for Global Change Research	IAI	www.iai.int/
International Council for the Exploration of the Sea	ICES	www.ices.dk/
International Geosphere-Biosphere Programme	IGBP	www.igbp.net/

Integrated Global Observing Strategy	IGOS	www.igospartners.org/
International Human Dimensions Programme on Global Environmental Change	IHDP	www.ihdp.org/
Integrated Marine Biogeochemistry and Ecosystem Research	IMBER	www.imber.info/
Intergovernmental Panel on Climate Change	IPCC	www.ipcc.ch/
International Research Institute for Climate and Society	IRI	iri.ldeo.columbia.edu/
Land-Ocean Interactions in the Coastal Zone	LOICZ	www.loicz.org/
National Oceanographic Data Center (US)	NODC	www.nodc.noaa.gov/
Ocean Observation Panel for Climate	OOPC	ioc.unesco.org/oopc/
Past Global Changes	PAGES	www.pages-igbp.org/
North Pacific Marine Sciences Organization	PICES	www.pices.int/
Global Research System for Analysis, Research and Training	START	www.start.org/
World Climate Research Program	WCRP	wcrp.wmo.int/

Table 1. Examples of international organizations and programs dealing with climate change and natural

2. Fisheries

Virtually all food production for our societies comes from agriculture, livestock farming, aquaculture, and fisheries. Among them, the last –fisheries- is the one where highest uncertainty is faced. This is partly due to the difficulty to maintain a deferred (if any) estimate of available biomass, and also because very few effective actions can be taken to counteract climate anomalies, other than reduce or increase fishing effort. Moreover, fisheries management has often been oversimplified by not considering the entire ecosystems and their ever changing nature. It is now recognized that the effectiveness of actions to sustain fisheries and fish populations depends on the capacity to consider and to minimize the negative impact of all sources of stress (fishing effort, climate, ecosystem-related).

In this article, some known mechanisms through which climate change impacts fish populations and fisheries are briefly reviewed, including some case studies to illustrate impacts at different time scales, aiming at providing some views on potential adaptation management strategies.

3. Fisheries and climate

Climatic changes influence the numbers and distribution of fish species through abiotic factors such as water temperature, salinity, nutrients, sea level, current conditions, and amount of sea ice. From these, temperature is probably the most widely recorded variable, and one usually regarded as indicator of more complex ocean processes. Changes in temperature can be related to winds and ocean currents, vertical mixing (enrichment), position of frontal areas, etc. In turn, these processes affect the abundance and variety of plankton (food) and its consumers (fish) and, together with the direct physiological effects of temperature, fish spawning, early stages survival, and growth.

Populations respond to temperature variations in different ways; for example, during El Niño episodes, strong and rapid warming might cause diseases or mortality in some populations, delays in growth, withering and reproduction failures in others, and some might be able to compensate by changing their distribution and migratory patterns in latitude, depth, and distance to shore. Because of these differences in population's responses, other indirect impacts of climate variations upon fishes include changes in food availability and composition, and in the presence of competitors and predators.
FAO scientists have classified fish populations on the basis of their long term variability patterns; they included steady state (i.e. populations showing no abundance or distribution changes), low frequency, cyclic, irregular, high frequency, and spasmodic. Of course, many variations to these patterns could be included, one of them being the pulse-like (showing strong abundance increase pulses during only one or two years). The pattern of variability tends to correspond to life history traits, with the highest variations in fast-growing, short-lived pelagic species, whereas low-variability stocks tend to be long lived, slow growing demersal fishes.

4. Climate changes in the interannual to multidecadal scales

4.1 ENSO impacting fisheries

El Niño-Southern Oscillation (ENSO) is a global coupled ocean-atmosphere phenomenon, with profound impacts on marine and terrestrial ecosystems at many locations of the world. It is by far the most prominent inter-annual variability signal. ENSO is frequently represented by the southern oscillation index (SOI), a time series of atmospheric pressure differences between Darwin (Australia) and Tahiti.

The Eastern Pacific Ocean fish populations are directly affected by warm temperature, nutrient-poor waters replacing the cold, nutrient-rich surface water of the Humboldt Current, which normally supports the most massive single-species fishery in the world ocean. The ocean signal is then transported along the coast, reaching as north as Alaska and as south as Chile during the strongest events. Direct ocean effects are related to temperature and reduction in biological productivity.

Another route of ENSO forcing the marine ecosystems is through the atmosphere. Large areas of the eastern Pacific coast are upwelling systems forced by equatorward winds: most of the Humboldt current (Peru and Chile), the California Current (from west Baja California peninsula in Mexico up to the southern part of the west coast of Canada), and the eastern coast of the Gulf of California. Also, offshore wind jets driven upwelling occur at Tehuantepec, Papagayo and Panama. Depending on several factors, such as the time of the year and the intensity of events, atmospheric teleconnections might change wind patterns, affecting upwelling and the entire system functioning. Atmospheric teleconnections is the mechanism underlying ENSO impacts in most of the planet.

A common response to ENSO warming is the poleward movement of populations, to avoid areas that became too warm or to take advantage of food resources in areas that were previously too cold for them. In any case, several species change distribution with the resulting forcing on fishing systems. For example, sport fishing species, like marlin and billfish, abandon the typical tourist destinies such as Los Cabos, and become available along the west US coast, completely changing the tourism patterns and strongly impacting local economies. It is interesting noting that not all this short term (typically less than 3 years) poleward fauna extensions are linked to ENSO events, as has been documented at least for the California Current System, indicating the existence of other mechanisms resulting in the same pattern.

Interesting and encouraging is the case of the Skipjack tuna (*Katsuwonus pelamis*), a massive large pelagic species mostly fished at the western equatorial Pacific warm pool. During ENSO events, population changes distribution together with the warm pool (moving eastward), and consequently its abundance and the associated catches. The very close association between skipjack tuna catch and ENSO is encouraging since, even when ENSO cannot still be forecasted, the mechanism governing its evolution are fairly well understood, and early warnings are already operative.

Of course, populations of benthic species cannot compensate warming by shifting latitude. In many cases, some degree of depth increase might compensate, but for many bottom associated populations ENSO represent a strong cause of natural mortality, and population dynamics alterations.

An important observation is that, even when negative impacts of warming are strong on marine fauna, the short duration of ENSO events result in many of the populations and ecosystems being able to recover after a year or so. For example, the Peruvian anchovy fishery occurs in the place of the Pacific under the strongest ENSO influence, was impacted but quickly recovered after each of the three major El Niño events in its history (1972/73, 1982/83 and 1997/98), even when these happened at very different abundance levels (highest, lowest, and near highest) abundances. Some fishing industries might also be able to rapidly recover, but for many of them two years of fishing failure can represent bankruptcy.

4.2 Other interannual signals

One particular mode of interannual variability occurs in several invertebrates, especially sea scallops, from some regions of the world. This pattern involves a sudden abundance increase, in one to two years, in one or more orders of magnitude, only to turn back to “normal” abundance levels just afterwards. These pulses often create huge fisheries expectations and investments, and result in strong economic failures and regional scale social problems. The mechanisms underlying these pulses are unclear, but likely largely dependent on the occurrence of particular, uncommon environmental conditions resulting in abnormal high recruitment pattern.

4.3 Pacific Decadal Oscillation

The Pacific (inter)decadal oscillation (PDO) is a recognizable pattern of sea surface temperature anomalies in the North Pacific, with no understood associated mechanism, but two relatively well characterized phases: a "positive" one corresponding to an Aleutian low pressure system deepened and shifted southward, sea surface temperature (SST) being anomalously warm along the coast of North America and cool in the central Pacific, coastal upwelling enhanced, mixed layer depth shoaled within the

Alaska gyre, and geostrophic transport increased into the Alaska Current from the westwind Drift. During the "negative" phase of the PDO, conditions are generally the opposite. This oscillation has been shown to impact fish populations in the North Pacific, and a growing body of evidence indicates impacts in the southern hemisphere. Often regarded as an interdecadal signal, the long reconstructions indicate higher energy in the 15-25 yrs and also in lower frequencies.
The signal was first described and named after analyzing several biological and physical time series, including salmon catches, one of the most important fish resources in North America. Northeast Pacific salmon populations vary at low frequency, closely related to the PDO, although not all populations are directly related; in fact, populations off Alaska and north Canada appear to be in opposite phase to those of California and Oregon. It has been suggested that during the positive PDO phase, water column stability increases in the northern area, resulting in greater biological productivity and more food for the salmon, while downwelling and weakened nutrients supply occur in the south (California). Other important North Pacific resources changing in apparent association with the PDO include cod, pollock, flounder, and halibut.

4.4 North Atlantic Oscillation

The North Atlantic Oscillation (NAO), described as the pressure differences between the Azores and Iceland is one of the oldest known natural weather patterns. It has two phases, each causing distinct weather conditions around the North Atlantic, and explaining around 50% of many of the ocean variables (air at surface temperature, sea temperature, sea ice coverage). High NAO generally means stronger southwest winds over the Barents Sea region (east), warmer sea surface temperatures, and sea ice tending to be pushed farther northward. Over the Labrador Sea (west), in these same years, the northwest winds carry cold Arctic air masses farther south, causing winter air temperatures to decrease and resulting in earlier, more, and farther south ice formation. The low NAO causes the opposite condition. This, so called “seesaw” pattern, impacts most natural resources and human activities in the North Atlantic, including agricultural harvests, water management, energy supply, and fisheries.

Probably the best example is cod, the most important fish resource in the North Atlantic, one of the few fisheries holding records for more than half a millennium, and probably the most extensively studied. Its catch fluctuations have been successfully associated to NAO variations in different areas, including the North Sea, the Labrador and Newfoundland, and the Barents Sea cod stock. It has been documented how temperature and food availability and quality, both determined by NAO variations, directly affect cod recruitment, growth, survival, distribution, and predator-prey interactions. Similarly, catch records of the European herring in the North and Baltic Seas, dating back to the 10th Century, have been linked to variations of the NAO and the resulting strength and pattern of southwesterly winds.

4.5 Multidecadal regimes

Several physical and biological variables show differences between periods of some 40 to 70 years. Understanding mechanisms underlying these fluctuations is hard since record and collection of long time series are still too limited, and collection of new, oriented data will likely take several decades. It has been proposed that multidecadal fluctuations in the Pacific have basinwide effects on sea surface temperature and thermocline slope, similar to what happens during ENSO events, but on longer time scales. During cool eastern boundary regimes, the basin-scale sea level slope is accentuated (lower in the eastern Pacific, higher in the western Pacific). A lower sea level is associated with a shallower thermocline and increased nutrient supply and productivity in the eastern Pacific; the inverse occurs in the western Pacific. In addition to thermocline and SST, there are regime shift changes in the transport of boundary currents, equatorial currents, and of the major atmospheric pressure systems. Some studies have suggested this mode of variability is associated with the PDO pattern, which shows a frequency peak in the 50 to 70 yrs frequency. However, since the NAO and other indices also show these variations, the multidecadal signal is often regarded as global.

Multidecadal variability and its impacts on fish resources became only recently widely accepted, although they were detected long ago. In the 1880s, a European scientist named Ljungman published an analysis of the Baltic herring catch fluctuations going back to the 8th century, where he suggested a 55-year cycle in the natural conditions of the whole region where herrings occur, forcing the schools to change their spawning and sojourn places. Another key contribution was the detection of the now called Russell cycle, showing variations of around 50 years in some plankton species abundance at the English Channel. Examples also include the detection of periodic fluctuations in the climate and hydrographic regime of the Barents Sea, which have been reflected in variations in commercial production over the past 100 years, and similarly, in the northwest Atlantic Ocean, cod variability and water temperature show cycles of 50 to 60 years.

The most compelling case is probably the fluctuations of sardines and anchovies described since the early 1980s, the so called Regime Problem. It is likely that small pelagics show particularly strong interdecadal fluctuations because of their populations reaching very high biomass and growing very fast, partly due to their very close connection to primary productivity. Landings of sardines show synchronous variations off Japan, California, Peru, and Chile, as population flourishing for 20 to 30 years and then practically disappearing for similar periods. Periods of low sardine abundance have been marked by dramatic increases in anchovy populations.

The Benguela Current sardine and anchovies, in the Atlantic, appear to be also in synchrony, but opposite in phase (i.e. sardine flourishing during periods of high anchovy in the Pacific, and vice versa). Even when the mechanism is still unknown, scientists are looking for one thought to be similar in all cases (cycles and locations), linked to large scale atmospheric or ocean forcing and, some argue, relatively simple and direct. The Regime Indicator series (RIS), synthesized from the catch series of the four mentioned systems, has been related to the low frequency component of different climate series, including the PDO and the NAO. Further, as demonstrated trough paleoreconstructions based on sardine and anchovy scales deposited in anaerobic marine sediments, and also because synchrony takes place even when different fishery management schemes exist between systems, fluctuations have been shown to be fishery-independent.

4.6 Regime shifts

Climate Regime shifts are part of the interdecadal variability, as changes between phases. Probably one of the most dramatic, sharp, and well documented climate regime change occurred in 1976-1977, reflected in several biological signals. Off California, this shift resulted in a reduced rate of supply of nutrients to a shallower mixing layer, decreasing seawater productivity and zooplankton biomass and causing reductions in kelp and sea birds. It was also widely documented as affecting salmon production of several species at different locations in the North Pacific, and also to an abrupt change in the southernmost extent of sea ice in the Bering Sea, in turn affecting the distribution of Walleye pollock and Arctic cod. This shift has been widely recognized in a myriad of North Pacific climatic and biological time series. Some indices suggest a more gradual change, though many reflect a rapid change.

Another well documented case of climate regime shift, smaller in geographic coverage, but compelling for the extent of the monitoring, was the one that occurred in the ocean conditions around the Northwestern Hawaiian Islands in the late 1980s. Biological effects where detected at several trophic levels, from seabirds and monk seals to reef fishes and spiny lobsters. One relevant aspect of this study is that fishing impacts and natural changes in the dynamics of the ecological community where isolated taking advantage of the possibility of comparison of exploited grounds and non-fished areas at separated reefs. Further, changes in abundance and distribution were documented in populations not subject to fishing, both predators and low trophic level species. The declines in spiny lobster were fastest on one of the harvested reefs, but declines were also observed in a non-harvested refuge. The shift in environmental conditions around the Hawaiian islands appear to be tied to a shift in ocean conditions around 1989 associated to changes in the Aleutian Low Pressure System.

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Biographical sketch

Salvador E. Lluch-Cota is a fisheries oceanographer working for the Fisheries Ecology Program at the Northwest Biological Research Centre, Mexico (CIBNOR). He received his undergraduate degree in Marine Biology from the Autonomous University of Baja California Sur (UABCS), his Master's from the Interdisciplinary Centre for Marine Sciences (CICIMAR) and his doctorate from CIBNOR. His work has focused on the effects of climate variations on marine ecosystems, specially the low frequency fluctuations in small pelagic fisheries. His background includes analyses of satellite-derived information, ecological effects of ENSO, and development of monitoring and forecasting models for physical-dependent ecological processes. He serves as research projects coordinator in the fields of climate change modular modeling, and linkages between human and biophysical processes in coastal ecosystems.