Climate change and long-term fluctuations of commercial catches

The possibility of forecasting

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This document presents the results of a study undertaken under contract to FAO by Professor Leonid B. Klyashtorin of the Federal Institute for Fisheries and Oceanography, Moscow, Russian Federation (e-mail: Klyashtorin@mtu-net.ru) . The study was inspired by discussions with FAO staff following a seminar given by Professor Klyashtorin in Rome in which he presented the results of previous work. Several people contributed to improvement of the document in various ways, including Dr Gary D. Sharp of the Center for Climate/Ocean Resources Study, Monterey, California, USA and Dr Paul Medley and Dr Gudrun Gaudian of Alne, Yorkshire, UK.

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ABSTRACT

The main objective of the study was to develop a predictive model based on the observable correlation between well-known climate indices and fish production, and forecast the dynamics of the main commercial fish stocks for 5–15 years ahead.

Populations of the most commercially important Atlantic and Pacific fish species - Atlantic and Pacific herring, Atlantic cod, European, South African, Peruvian, Japanese and Californian sardine, South African and Peruvian anchovy, Pacific salmon, Alaska pollock, Chilean jack mackerel and some others - undergo long-term simultaneous oscillations. Total catch of these species accounts for about 50% of total fish harvest over Atlantic and Pacific.

It was found that the dynamics of global air surface temperature anomaly (dT), although in correlation with the long-term dynamics of marine fish production, is of poor predictive significance because of high inter-annual variability and a long-term trend. The Atmospheric Circulation Index (ACI), characterizing the dominant direction of air mass transport, is less variable and in closer correlation with the long-term fluctuations of the main commercial stocks (r = 0.70-0.90).

Spectral analysis of the time series of dT, ACI and Length Of Day (LOD) estimated from direct observations (110-150 years) showed a clear 55-65 year periodicity. Spectral analysis of the reconstructed time series of the air surface temperatures for the last 1500 years suggested the similar (55-60 year) periodicity. Analysis of 1600 years long reconstructed time series of sardine and anchovy biomass in Californian upwelling also revealed a regular 50-70 years fluctuation. Spectral analysis of the catch statistics of main commercial species for the last 50-100 years also showed cyclical fluctuations of about 55-years.

These relationships were used as a basis for a stochastic model intended to forecast the long-term fluctuations of catches of the 12 major commercial species for up to 30 years ahead. According to model calculations, the total catch of Atlantic and Pacific herring, Atlantic cod, South African sardine, and Peruvian and Japanese anchovy for the period 2000–2015 will increase by approximately two million tons, and then decrease. During the same period, the total catch of Japanese, Peruvian, Californian and European sardine, Pacific salmon, Alaska pollock and Chilean jack mackerel is predicted to decrease by about four million tons, and then increase. In the next 15 years, total catch of main commercial species in the North Pacific is predicted to decline by 1.5 –2 million tons, while in the North Atlantic it is predicted to increase by about 1.7 –2 million tons. The probable scenario of climate and biota changes for next 50-60 years is considered.

Key words: Global climate change, Stock fluctuations, Climate-production cycles, Pacific, Atlantic.

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1. BACKGROUND

Marine fish populations show evidence of significant long-term fluctuations in abundance, which have implications for medium and long term forecasting of fish catches. The relationship between these fluctuations and large-scale climate changes is an important scientific and economic concern.

Simultaneous outbursts of sardine and anchovy populations in both North and South Hemispheres suggest that the fish populations are governed by the same global climatic events (Lluch-Belda *et al.* 1989, 1993; Kawasaki 1992a, b; Shwartzlose *et al*. 1999). An even more interesting phenomenon, pointed out in a number of publications, is regular synchronous outbursts of Japanese, Californian, and Peruvian sardine catches in different regions of the world ocean.

A reliable correlation between the long-term stock fluctuations and global climate characteristics has been ignored until recently, and the mechanisms that initiate, sustain and terminate such outbursts are still unclear. Beginning from the early 1990s, several attempts have been made to correlate regular fluctuations of sardine and anchovy stock with the dynamics of global and regional climatic indices. Kawasaki (1994) first applied the concept of cyclic climate changes (Shlesinger and Ramankutti 1993) to explain regular changes in the Japanese sardine catches for the last 350 years.

There are a number of new data sets on long-term climatic changes influencing gross production of zooplankton and nekton in North Pacific (Brodeur and Ware 1995). Synchronous changes in some climatic indices and abundance of crustaceans, fishes[1], and sea mammals were reported to occur in the tropical Pacific (Polovina *et al*. 1994).

A special issue of the journal *Fisheries* (1990) was dedicated to the synchronous character of climatic changes and populations of sea and fresh-water fish species. Francis (1990) analysed climate changes in relation to the fluctuations of the world commercial catches. Regier and Meisner (1990) estimated probable changes in the population of some species of fresh-water species as a possible consequence of global warming. Glanz (1990) tried to forecast the impact of expected climate changes on the world fishery. In spite of challenging titles, all these papers consider the fish stock fluctuations in response to various scenarios of "global warming" only.

The topical workshop *Cod and Climate* (1994) comprised a range of papers dedicated to the long-term dynamics of commercial stock and considered most important fish species in the North Atlantic in the context of global climate change. Jonsson (1994) carried out a statistical analysis on the reconstructed time series of Iceland cod catches for 350 years and found a periodicity in catch dynamics of approximately 60 years. The periodicity apparently does not depend on the intensity of fishery and it is argued that it is caused by regular climate changes. Fluctuations of the cod catches in western and eastern Atlantic for the last 80 years have occurred almost simultaneously, which is likely to be caused by the same climatic mechanism (Garrod and Shumacher 1994).

Although most of the papers presented at the *Cod and Climate* include important information, they described the phenomenon of "climate–fishery correlation" rather than explained it. It is important, however, to analyze possible causal mechanisms linking catches and climate, and develop an approach to predict climate-dependent changes in fish production.

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1 A number of commercial species mentioned in this paper using their common names (widely accepted in the world scientific community) have alternative names in the FAO statistics, as follows:

Common name used in the paper	Name in FAO nomenclature
Japanese sardine	Japanese pilchard
Peruvian sardine	South American pilchard
Californian sardine	California pilchard
European sardine	European pilchard
S.African sardine	Southern African pilchard
Peruvian anchovy	Anchoveta

A dependence of Japanese sardine catches on climate changes (expressed as surface air and water temperature on the hemispheric scale) was reported by Kawasaki (1992a). The same is true for Californian sardine (Lluch-Belda *et al*. 1992). Beamish and Bouillon (1993) showed that the long-term fluctuations of the Pacific salmon catches are in agreement with the dynamics of the regional Aleutian Low Pressure Index (ALPI). The latter is known to be one of the main climate-forming factors for the North Pacific.

Analysis of the ALPI dynamics over the last 93 years made it possible to forecast a probable decreasing trend in salmon populations in the early 21st century. Klyashtorin and Smirnov (1995) found a close correlation between the catch dynamics of Pacific salmon, Japanese, and Californian sardines, on the one hand, and the dynamics of hemispheric temperature anomaly for the last 75 years, on the other. Based on the climatic and production trends, the authors suggested that salmon populations were likely to decrease in the first decade of the next century (Klyashtorin 1997).

Bakun (1990, 1996) demonstrated a close correlation between the long-term fluctuations of the upwelling index in the most productive zones of the world ocean and catch dynamics of abundant, small pelagic fishes. The author believes that the global climate changes are accompanied with significant changes in the atmospheric circulation, direction and velocity of largest oceanic streams, and upwelling intensity. This, in turn, affects the rate of nutrient transport into the euphotic upper ocean layer and causes considerable changes to the oceanic primary production and fish harvest.

With this background, FAO (1994, 1996, 1997a, b) has initiated a range of detailed research programmes to analyze the state and perspectives of the world fishery and stimulate the development of new approaches to long-term forecasting of the fish stock dynamics.

Lluch-Cota and others (FAO 1997b) analyzed the dependence of sardine, anchovy and other pelagic species on selected regional climate indices worldwide and in the Pacific. The authors revealed close correlations between the dynamics of regional climate and production indices, but did not attempt to estimate future changes in fish production.

Beamish *et al*. (1999) considered correlations between the dynamics of Pacific salmon catch and a range of global and regional climatic indices in the Pacific for the most recent 100 years. They showed that the catch fluctuations depend on the long-term natural (climatic) changes rather than only on the impacts of commercial fisheries. The authors discussed the applicability of various climatic indices to characterise commercial catches in the future, but did not suggest a clear approach to climate-based forecasting of salmon stocks.

Klyashtorin and Sidorenkov (1996) showed that the stock and catch dynamics of the 15 main commercial fish species in the Pacific is in good agreement with the dynamics of the global temperature anomaly (dT), Atmospheric Circulation Index (ACI), and global geophysical index Length Of Day (LOD), which characterizes the earth rotation velocity.

The concept of synchronous cyclic fluctuations of the climate and fish production was used to predict the long-term stock and catch dynamics of Pacific salmon into the late 1990s and early 2000s (Klyashtorin 1997). The accuracy of the prediction is confirmed by recent statistical data on commercial catches of Pacific salmon and sardines.

Similarly, Klyashtorin (1998) demonstrated a close correlation between the peculiarities of the hemispheric atmospheric circulation and catches of 12 commercially important fish species, which constitute 35 to 50% of the total marine catch. Regular alternation of roughly 30-year "climatic epochs" (this study is described in more detail below) was shown to correspond to the outbursts of some fish species. The author believed that the analysis of regular fluctuations of popular climatic (dT, ACI) and geophysical (LOD) indices makes it possible to forecast the population dynamics of main commercial species in the Atlantic and Pacific for 10–15 years ahead.

In spite of some progress in our understanding of the climate change and fluctuations of commercial fish stock, long-term forecasting calls for further development of methods. To improve the present general concept of the climate–production dependence, it is necessary to substitute the simplistic correlative model with a better established, digital prognostic model intended for reliable forecasting of commercial catch of each of 12 main commercial species.

The evolution of our understanding of the "climate-stock" dependence may be presented as follows:

- 1960–1980s. First reports on the phenomenon of synchronous outbursts of sardine and anchovy in different regions of the world ocean.
- 1980/90s. Development of the concept of sardine and anchovy stock as dependent on the dynamics of several global and regional climatic indices.
- The late 1990s. New data indicate a close correlation between the climate changes and stock dynamics of ten main commercial species (including but not limited to sardine and anchovy). The first ideas on regular 50-70 year climate change and regular 25-30 year alternation of ACI epochs («zonal» and «meridional»). First approximation to the long-term forecasting of commercial stock dynamics was undertaken.
- Year 2000. An approximation to the climate-based prognostic model of commercial stock for 10–12 commercial fish species. Estimation of probable trends in fish production over vast regions (North Atlantic, North and South Pacific).

The main purpose of this work is to develop a predictive model based on the observed and logically consistent correlations between climate and fish production and forecast the dynamics of main commercial fish stocks for periods of 5–15 years ahead of the observed fisheries catch changes. To do that, it is necessary to forecast the future climate changes, which can be achieved using retrospective analysis of the long-term time series of some principal climatic indices.