C4. FISHERIES AND LONG-TERM CLIMATE VARIABILITY

by Jorge Csirke and Marcelo Vasconcellos *

INTRODUCTION

An important source of concern for fishers, fishery scientists and fisheries administrators dealing with most wild fish stocks from the oceans is the high variability of fish abundance and fish catches. This makes even short-term planning a rather difficult task as in those cases not even good statistics describing past and present catches are, by themselves, usable proxies for what could be produced in the years to come. Experience has shown that much more needs to be known about the natural fluctuations in fish stock abundance, their causes and trends, and how to deal with them.

Persisting attempts have been made to control or alleviate year to year changes in fish catches and stock abundance. For several decades fisheries scientists and administrators had concentrated major efforts in controlling fishing pressure and in tackling the overfishing problem on the assumption that environmental factors and natural causes of change in stock abundance could be taken as a random or a constant parameter. However, the relatively high proportion of fish stocks that over the years have been overexploited and depleted suggest that the attempts to tackle the overfishing problem and control resources fluctuations by controlling fishing pressure as taught by Russell (1931), Beverton and Holt (1957), Ricker (1958) Gulland (1969) and others, have not always been a successful undertaking.

Causes for failure in maintaining exploited fish stocks in healthy condition and in preventing or avoiding their overexploitation and eventual depletion are at least twofold: the variable character of Nature and the poor performance of fisheries management and decision making. In several cases large and unpredictable natural changes in stock abundance could be blamed for the decline of fish populations and the collapse of important fisheries. However, greediness and poor management, including feeble application and enforcement of accepted guidelines and regulations are also to be blamed, and often solely, for the severe decline of important fish resources and the collapse of their fisheries.

Although important, not much will be said here on the latter, nor on the short-term natural causes of stock fluctuations to focus on some relevant aspects of natural long-term changes in climate that may affect fisheries by causing wild fish stocks to vary, even widely, with time.

FISHERIES LONG-TERM FLUCTUATIONS

An important meeting that looked into the matter of changes affecting fish stocks and fisheries was organized by FAO in 1983, where different causes of change, fluctuation patterns, their possible causes and relationship with environmental factors and suggested research and management strategies to face them were discussed and recounted (Sharp and Csirke, 1983; Csirke and Sharp, 1984). While at first it was mostly considered a scientific problem, as world fisheries developed, and as more and longer fishery records became available, long-term changes affecting fisheries have attracted more the attention of fishers, fisheries managers, policy- and decision-makers and the general public.

The first scientific report of long-term fluctuations in herring abundance was published in 1879 based on observations made since the sixteenth century. Ljungman (1879, cited in Lindquist, 1983) described the so-called "herring periods" in the Bohuslän archipelago, Sweden, which lasted from 30 to 60 years. Since then, many more reports dealing with long-term fluctuations in marine capture fisheries have appeared, and of particular relevance are Kawasaki's attempts to explain why some pelagic fishes have wide fluctuations in their numbers (Kawasaki, 1983). His report showing the synchronized catch patterns of the three main Pacific sardine (or pilchard) species of the genus *Sardinops* since the early 1900s convinced the scientific community that there was a clear underlying natural cause for the blooms, peaking and general return to very low levels of these resources (Csirke and Sharp, 1984). Kawasaki's theories found confirmation as world fisheries expanded and more evidence of long-term fluctuations in fish abundance emerged. This is shown, for instance, through the update of the main pilchard (genus *Sardinops*) catches in

* FAO, Marine Resources Service, Fishery Resources Division

Figure C4.1 where, however, it is noted that since the early 1990s the California pilchard (or sardine) does not follow the trend observed in other cogeneric species in the Pacific. Catches of California pilchard peaked in 2002, the last annual data recorded, while that of South American and Japanese pilchards have been declining sharply after peaking in 1985 and 1988, respectively.

There seems to be at least two sets of reasonable explanations for the continued increasing trend in California pilchard catches. A sequence of good year classes, particularly in 1998, and high stock biomass off California, which has stabilized at around 1 million tonnes since 1999 (Conser *et al.,* 2002) is one. The 1997-98 "El Niño" might have had an influence here. Also, there is an intense Mexican fisheries inside the Gulf of California (which in recent years represent ca. 60 percent of total catches) while catches off Ensenada are much lower, the same as off the Pacific coast of USA, where the fishery is tightly regulated under a quota management scheme intended to protect the stock and prevent overfishing. Both sets of factors might have a role in delaying the declining phase of this recent high abundance cycle of California pilchard.

As will be described later, long-term fluctuations in fish abundance and/or catches have been reported for several other important fish stocks of the world, including cods, salmons and tunas.

Figure C4.1 - Observed long-term catch variability of Japanese pilchard (*Sardinops melanostictus*) in the Northwest Pacific, California pilchard (*S. caeruleus*) in the Eastern Central Pacific and South American pilchard (*S. sagax*) in the Southeast Pacific (updated after Kawasaki, 1983, Csirke, 1995 and FAO, 1997)

South American pilchard (max. 6.5 million t in 1985)
California pilchard (max. 722 thousand t in 2002)
Japanese pilchard (max. 5.4 million t in 1988)

Possible causal mechanisms

There have been increased attempts to relate fisheries cycles to available long-term climatic variability signals as a means of identifying the possible causal mechanisms of fish fluctuations. In the last two decades several relevant research efforts have been devoted to describing and analysing long-term fluctuations in the abundance of commercial species and the possible relationships between ocean climate and fish stock size. Amongst these, one of the best documented cases in the literature is the above mentionned regular synchronous outbursts of sardine (or pilchard), and also anchovy populations in both northern and southern hemispheres which suggest that fish populations are governed by similar global climatic events. Following his earlier work, Kawasaki (1994) was one of the first to develop further the concept of cyclic climate changes to explain the regular cycles in the Japanese pilchard catches in the last 350 years.

The analysis of reconstructed time series of cod catches in the North Atlantic have also showed synchronous oscillations in western and eastern stocks which are likely to be caused by the same climatic mechanisms (Garrod and Schumacher 1994; Jonsson 1994). Others have analysed possible links between global warming and fish stock fluctuations (Francis, 1990; Glantz, 1990; Regier and Meisner, 1990). Kawasaki (1992) and Lluch-Belda *et al.* (1992) suggested the dependence of Japanese and California pilchard catches on changes in surface air and water temperature in the northern hemisphere. Beamish and Bouillon (1993) showed that fluctuations in Pacific salmon catches are in agreement with the dynamics of the regional Aleutian Low Pressure Index, which is recognized as the main climate-forcing for the North Pacific. Bakun (1990; 1996) related the long-term fluctuations of small-pelagic fishes with changes in upwelling intensity, and according to the author, global climate changes are accompanied with significant changes in atmospheric circulation and in upwelling intensity. As the largest populations of small pelagic stocks are associated with centres of intense upwelling activity, any changes in upwelling intensity will affect considerably the oceanic primary production and fish harvest in these areas. Also, after analyzing long-term time series of bluefin tuna catches from traditional
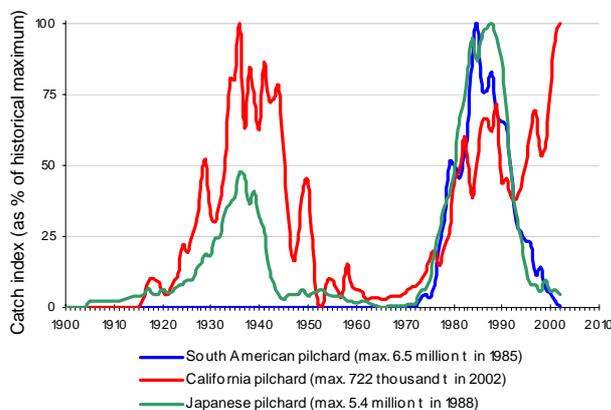
Mediterranean and Atlantic trap fisheries spanning for more than 300 years, Ravier and Fromentin (2001) showed that the eastern Atlantic bluefin population displays fluctuations with a period of 100-120 years and also cyclic variations of about 20 years. The long-term fluctuations were strongly and negatively correlated to trends in temperature. The close relationship between catches and temperature seems to be best explained by changes in the migration patterns of bluefin tunas, and consequently changes in their availability to the fixed gears, imposed by modifications in oceanographic conditions of spawning areas (Ravier and Fromentin, 2004).

In line with its role as the main specialized UN agency responsible for fisheries matters, FAO has supported several studies to improve knowledge on possible relationships between climate and fisheries changes, its causes and mechanisms, as well as the possible uses and applications of this improved knowledge for world fisheries conservation and development planning. The FAO Expert Consultation that analysed these changes (Sharp and Csirke 1983; Csirke and Sharp 1984) was an important attempt in this direction. Other attempts have followed, and the reviews by Klyashtorin (2001) and Sharp (2003) are some of the most recent ones.

The changes in abundance of a number of species that have long-term fluctuations, have shown to have some correlation with climatic indices. Long-term observations of Japanese pilchard outbursts and atmospheric temperature indices (Figure C4.2) have led to proposals that the long-term regular changes in Japanese pilchard catches could be explained by cyclic climate changes (Kawasaki, 1994). More recently, available FAO and other data sets of world fisheries catches were analysed by Klyashtorin (2001) in an attempt to explore the possible relationships between various climate indices and the catches of selected groups of fish stocks. He also developed a time series model based on well-known climate cycles to forecast possible trends in main commercial fish catches from 5 to 15 years into the future. While such forecasts must be taken with great caution, their results are both provoking and interesting enough to merit further attention and analysis. Recent theories and findings by Klyashtorin are based on the analysis of the possible relationship between fish abundance indices, as reflected by annual catches, and climate changes. In this context, the

term "climate change" refers to large-scale, long-term effects (or shifts from one climatic state to another) that seem to respond to deterministic cycles, rather than individual climatic events, such as El Niño, or long-term trends, such as global warming.

The causal mechanisms that drive most of the long-term periodic fish abundance fluctuations analysed by Klyashtorin remain unclear, and some of his findings are still working hypotheses. However, the signals and trends in climatic indices and historical fish landings that emerge from his work are of utmost interest, and merit close study. Through this, it is hoped that the mechanisms governing climate change and long-term fish production variability will be better understood and used for management purposes.

The argument put forward in most of the cases discussed by Klyashtorin is that biomass and catches are ultimately driven by climate fluctuations. This runs counter to the conventional wisdom of fisheries management, which considers that biomass and catches are driven mostly by fishing pressure and that environmental effects of fish stocks are mostly random or stochastic. In fact, what the climate-fisheries studies have demonstrated is that the environmental effects on fish populations are characterized by a long sequence of patterns and processes that tend to fall into rhythms or regimes (Sharp, 2003). Given enough observations about causal links one hopes that transitions from one regime to the other can be forecasted.

It has already been suggested (Bakun, 1996) that upwelling intensity is linked to large-scale climatic effects, which ultimately affect the rate


Figure C4.2 - Cyclic temperature fluctuations and Japanese pilchard (*S. melanosticus*) outbursts, years 1600-2000 (from Klyashtorin, 2001)
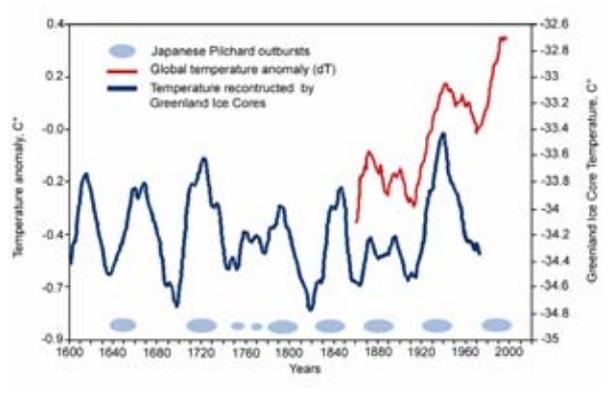
Figure C4.3. Periodicity of the zonal atmospheric circulation index (ACI), the detrended values of global temperature anomaly (dT) and negative length of day (-LOD) with lag-time unmodified (A, top) and with ACI and – LOD shifted 4 and 6 years ahead (B, bottom) (redrawn after Klyashtorin, 2001)
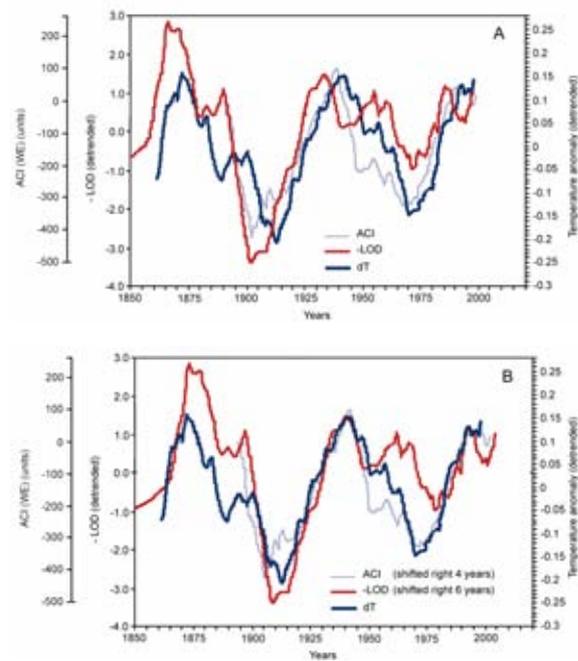
Figure C4.4. Dynamics of meridional (C) and zonal (WE) forms of the atmospheric circulation index (ACI) (A, top) and alternation of corresponding meridional and zonal circulation epochs (B, bottom) (from Klyashtorin, 2001)
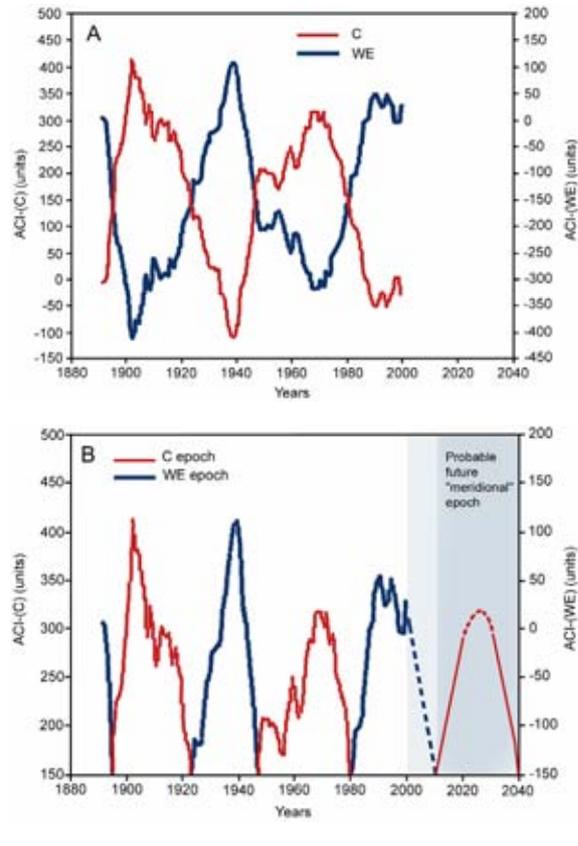
of nutrient transport into the eutrophic upper ocean layer, thereby changing primary production and, subsequently, fish production. However, while hypotheses relating climate to nutrient availability may be correct, there is no direct evidence of the mechanism, and no conclusive modelling of the causal relationship has so far been possible.

The work of Klyashtorin showed consistent correlation of climatic and geophysical indexes with manifestation of important processes related to fisheries. The indexes are the surface air temperature anomaly (dT), which is the most important index of global climatic change; the length of day (LOD), a geophysical index that characterizes variation in the earth rotation velocity; and the Atmospheric Circulation Index (ACI), which characterizes the periods of relative dominance of directional transport of air masses on the hemisphere scale. The LOD index is calculated as the difference between the astronomical length of day and the standard length of day. Time scales to calculate the LOD index are available from the records maintained by the International Bureau of Weights and Measures (http://www.bipm.org), and the time series of data cover more than 350 years of data.

The ACI index is calculated based on a classification system developed by Russian climatologists. According to this system, all observable variation in atmospheric circulation is classified into three basic types by the direction of the air mass transfer: meridional, zonal western and zonal eastern. Air mass transfers in each direction are calculated based on daily atmospheric pressure charts over the northern Atlantic and Eurasian region. The ACI index is defined by the number of days with the dominant type of atmospheric circulation, being expressed as an anomaly from the long-term average.

Spectral analysis of the time series of dT, ACI and LOD estimated from available direct observations (110-150 years) shows a common periodicity of 55-65 years (Figure C4.3). Spectral analysis of the reconstructed time series of air surface temperatures for the last 1 500 years suggests a similar (55-60 years) periodicity. Furthermore, the ACI observations show two alternating climatic periods, each of approximately 30 years duration, according to the dominance in air mass transport on the hemispheric scale (Figure C4.4).

Each 30-year period corresponds to a "circulation epoch" of meridional (C) and zonal (W+E) air masses transfers. Zonal epochs correspond to periods of global warming and meridional epochs correspond to periods of global cooling (Sharp, 2003). Long-term changes in global scale indexes (LOD) have also been associated with changes in regional processes in the Pacific, such as intensity of local upwelling and basin-wide sea level pressure (Sharp, 2003). That is, there is a direct wind-driven force that occurs in synchrony with LOD and that controls warm/cold regimes in the Pacific Ocean. These regimes are known to affect the marine fauna of the North Pacific, including the large populations of small pelagic fish. Studies in Eastern Boundary Ecosystems show for instance that anchovies thrive during cooler coastal upwelling periods. Pilchards prefer warmer conditions and seem to cope with the strong upwelling periods by subsisting in small colonies away from the upwelling influences (Sharp, 2003). Klyashtorin used the ACI and LOD as suitable climatic indexes for further investigation of long-term regular changes in catches of major commercial fish stocks.

CLIMATE-FISHERIES CORRELATION

Evidence of the relationship between climate and fisheries landings comes from two main sources: a few long-term indices of climate and fish stock size up to 1 700 years, which show similar cyclic patterns as well as correlation between series; and fluctuations in catches of 12 major commercial species in the Atlantic and Pacific, which have synchronized since 1900, corresponding to climatic indices over the same period. Both long- and short-term series appear to have a common cycle. The most pronounced periodicity of long-term fluctuations in catches for all time series (excluding anchovy) varies from about 54 to 58 years. The corresponding climate cycles (both measured and reconstructed) vary from 50 to 65 years (with an average of 56 years). Other less significant cycles (13 and 20 year fluctuations of summer temperature) may also be of interest, but so far no reliable correlation between these cycles and commercial catch fluctuations have been found.

According to the peculiarities of their long-term dynamics, Klyashtorin divided the 12 species that were examined in two groups. The first

Figure C4.5. Annual catch of Japanese pilchard (A, top) and Pacific salmon (B, bottom) in relation to the zonal atmospheric circulation index (ACI) (from Klyashtorin, 2001)
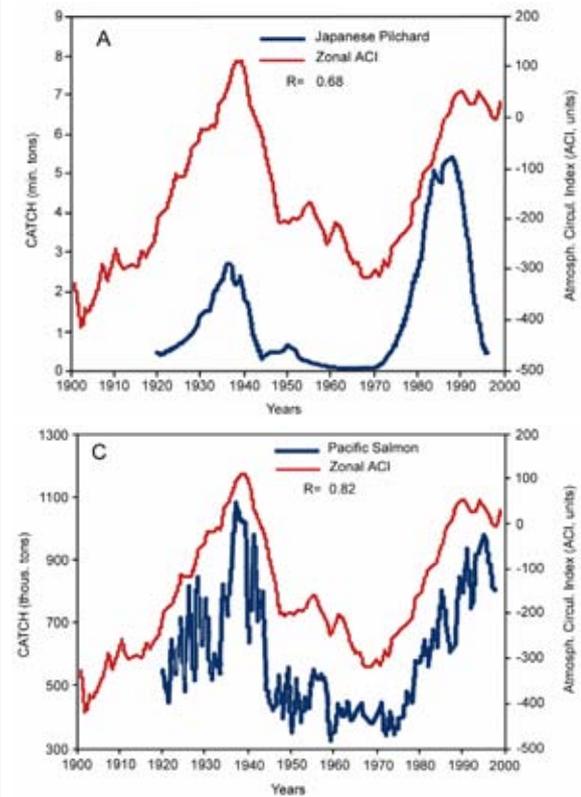
Figure C4.6. Annual catch of Atlantic cod (A, top) and Pacific herring (B, bottom) in relation to the meridional atmospheric circulation index (ACI) (from Klyashtorin, 2001)
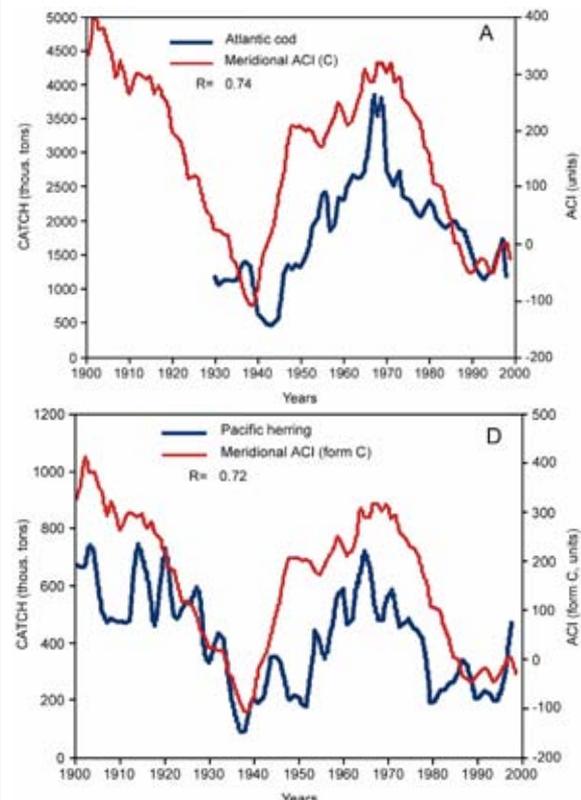
group consisted of Japanese, California and South American pilchard, Pacific salmon, Alaska pollock, Chilean jack mackerel and European sardine. Catch time series of these species show a maximum in the late 1930s and early 1990s and minimum in the 1960s. The second group comprizes Atlantic cod, Atlantic and Pacific herring, South African pilchard and Peruvian anchovy. It shows a production cycle opposite in phase, with maximum catch in the 1960s and the minimum in 1930s and 1990s. While the catch of the first group (Figure C4.5) are closely correlated with the zonal ACI curve, catches of the second group (Figure C4.6) are closely correlated with the meridional ACI curve.

Among the long-term cycles, Japanese chronicles contain historical information on Japanese pilchard abundance for the last 400 years (Figure C4.2). Changes in the availability and abundance of pilchards off Japan led to the development of several coastal fishing villages, as well as the collapse of others. The average cycle length is about 60 years, and periods of high abundance tend to coincide with warmer atmospheric periods.

Off the coast of California, anaerobic conditions in seasonally layered sediments have preserved fish scales from populations of small pelagic fish. Two time series of the abundance index could be reconstructed for pilchard and anchovy stocks for the last 1 700 years from these sediments (Baumgartner, Soutar and Ferreira–Bartrina, 1992). Although they demonstrate large fluctuations, these time series show no clear differences between the earlier period, when fishing was negligible, and the more recent period, when exploitation has become far greater.

Analysis of the long-time series of sediment scales indicated two principal oscillations in pilchard abundance: one occurring every 54 to 57 years, and the other every 223 to 273 years. The first of these oscillations is similar to that observed in both air temperature as measured from fossil ice cores and pilchard biomass, making it particularly important for fishery forecasting. Dominant fluctuation periods for anchovy are about 100, 70 and 55 years in duration. The increases in pilchard and anchovy abundance appear to be linked, respectively, to the two atmospheric regimes (zonal and meridional epochs) that have already been mentioned, suggesting that these two species may be favoured by different climatic conditions.

However, unlike other commercial pelagic species, the regular climate-dependent dynamics of Peruvian anchovy are greatly perturbed every 10 to 15 years by strong El Niño events, so the future catch dynamics of this species are not well approximated by a smooth "average" curve. In non-El Niño years about 70 to 90 percent of the total anchovy catch in the Pacific is Peruvian anchovy.

It is reasonable to expect that fish catches would have a greater correlation with corresponding regional climatic indices than with more global ones. However, the results obtained by Klyashtorin (2001) suggest that the catch dynamics of the main Pacific commercial species (Pacific salmon, Japanese, Californian and South American pilchard, Alaska pollock and Chilean jack mackerel) are in closer correlation with the global climatic indices, dT and ACI than they are with their corresponding regional indices. There is not as yet a satisfactory explanation for this.

One possible explanation for the weak correlation with regional indices is the tendency, in climate-fisheries analyses, to lump together data from wide regions and geographically separated stocks. That seems to be case for the populations of Pacific salmon. Analysing recruitment rates of multiple salmon stocks from different watersheds in British Columbia and Alaska, Peterman *et al.* (1998) concluded that environmental causes of variation in survival rates operate mainly on regional spatial scales. They showed, for example, that a decadal shift in productivity in the 1970s, as proposed by Klyashtorin, occurred only in salmon stocks from certain watersheds. This indicates that important environmental processes affecting salmon survival operate at regional scale, rather than at ocean-basin scale. In the case of Pacific salmon stocks the causes of changes in productivity are the result of a combination of both freshwater and marine processes which are still not completely understood.

FORECASTING POSSIBILITIES

One particularly interesting feature of the correlations between dT, LOD and ACI indices is that although the curves are very similar in shape, the changes in dT lags behind LOD by approximately 6 years (Figure C4.3) and behind ACI by 4 years. This coincidence makes it possible to predict dT dynamics for at least 6

years ahead. The observed time lag between climatic indices, their recurrent pattern in the past, and their synchronous oscillation with fisheries production has prompted Klyashtorin to forecast changes in climate and marine populations.

Assuming that the observed past correlation between fish catches and atmospheric regimes will continue in the future, Klyashtorin attempts to forecast total catches of a selected group of major commercial species by fixing the cycle periods at 55, 60 and 65 years (based on the climate cycle) rather than relying on estimates of the cycle length from the relatively short catch time series. His analyses suggest that a shift between the two alternative atmospheric regimes is, indeed, occurring. As a result, provided that the observed synchrony between fish and climatic epochs persists, and that fishing effort does not change substantially, production of the selected major commercial species over the next decade would be expected to decrease in the North Pacific and increase in the North Atlantic (Figure C4.7). Forecasting of the major commercial fish catches for the next 30 to 40 years is largely insensitive to the choice of periodicity within the 55 to 65 year range. Species such as Atlantic and Pacific herring, Atlantic cod, South African pilchard and Peruvian and Japanese anchovy would be expected to increase during 2000-2015, decreasing thereafter. During the same period, total catch of species such as Japanese, South American, Californian and European pilchard (or sardines), Pacific salmon, Alaska pollock and Chilean jack mackerel would be expected to decrease, increasing thereafter. Overall, the total catch of the main world commercial species considered in the analyses, and representing about one-third of world marine capture landings, would be expected to increase by 5.6 million tonnes by 2015, then to decrease by 2.8 million tonnes by 2030, due to climate effects alone.

CAUTIONS AND LIMITATIONS

Klyashtorin concluded that climatic periodicity serves as a basis for predicting production and catches of major commercial fish species. He warns however that his model is applicable to the abundant species only (commercial catch >1–1.5 million tonnes) yielded over large areas, such as North Pacific or North Atlantic as a whole.

One other limitation highlighted by the author is that forecasts will be valid only with the assumption that the intensity of commercial fishing does not change substantially from the average of the last 20-25 years.

As suggested by Sharp (2003) one important requirement for studying complex systems, such as the interaction between climate and fisheries, are reasonable monitoring schemes, operated for sufficiently long periods so they could capture the full system dynamics. In fisheries there are very few cases where time-series cover more than one or two complete rise and fall cycles for the populations involved. There are even fewer cases that are accompanied by observations of the forcing system(s) that directly or indirectly affect them. Data scarcity is, according to Sharp (2003), one of the main problems that limit the forecasting capabilities of the effect of climate on fisheries. To make matters even worse in this respect, most of the fishery data used in climatic analyses are from the last 50 years, a period which, according to the author, is notable for its lack of dynamics and low variance in comparison to century and longer time-scale records.

It is also important to consider that the 50 years of data available for most stocks examined by Klyashtorin (2001) are from a period marked by the most drastic changes in fishing effort and in the technologies for fish location and capture. These changes enabled fisheries to expand to areas not fished before and with a much higher efficiency. The analysis of trends in fisheries catches during this period has to take such effects into account. Finally, as components of ecosystems, fish stocks are linked to other

Figure C4.7. Observed (1920-1998) and forecast (2000-2040) catches changes for selected major commercial species in the North Atlantic and North Pacific (redrawn after Klyasthorin, 2001)
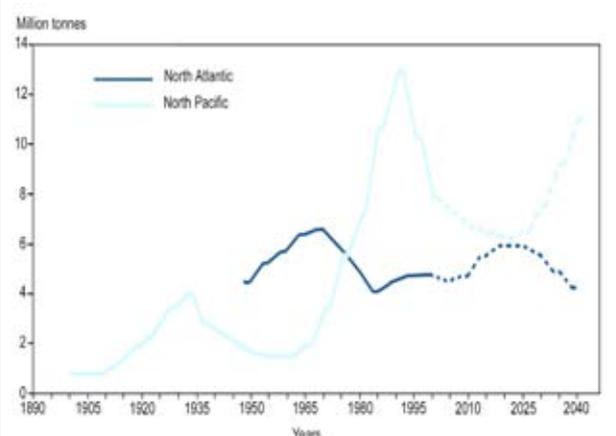
species through predator-prey and other types of interactions, therefore large removals of fish biomass by fisheries are expected to cause positive and negative responses in production of other resources, which may themselves be also target by commercial fisheries. There are many examples in the literature of changes of species dominance as a possible consequence of competition or predation release. For instance, Fogarty and Murawski (1998) showed evidence that a reduction of more than 50 percent of gadid and flounders biomass on Georges Bank due to fisheries has led to an increase in the abundance of dogfish sharks and skates. Attempts have been also made to link the observed alternations between pilchard and anchovy species to overfishing and trophic mechanisms. The most frequently visited hypotheses in the literature are food competition, and predation of adult anchovy/pilchard on the early life stages of the competing species (Vasconcellos, 2000).

In summary, any trends in fisheries catches during the last 50 years should be viewed as the result of the interaction of human (fisheries), ecological and climatic processes on fish populations, but their relative importance remains unknown. These processes are confounded in the time series of catch statistics; hence any forecast and correlations based on this data should be viewed with caution.

POLICY IMPLICATIONS

Climate changes can affect fisheries in both short and long term. While fisheries have developed mechanisms to cope with short-term environmental variations (e.g. seasonal calendars of activities), it is the long-term component of variability (between years and decades) that is less understood, normally unpredictable and most influential to fisheries sustainability.

The possibility of forecasting long-term changes in world capture fish production, based on observable indices of long-term climatic variability, raises justified scientific, economic and policy expectations and concerns. Management organizations tend to assume that fishing pressure is the major influence on the long-term productivity and size of wild fish stocks. It is commonly accepted that appropriate management could maintain stock size that are commensurate with sustainable high catches, and that the usual consequences of management

failure are depressed - and even depleted - stock sizes and lower yields. Recognition that, for some key species, deterministic long-term climate-driven impacts on stock abundance are, or could be, as important as suggested calls for a review of research and management strategies and objectives regarding fisheries of the species concerned, as well as of related species. Management responses to short-term fluctuations would have to take into account the possibility that underlying long-term deterministic fluctuations exist. Long-term management aims, which would typically involve capital investment, and social and infrastructure development, would also benefit from consideration of the long-term climate effects.

Overall, deterministic climate-driven increases and decreases in fish production do not seem to be of great global importance, as increases in a group of stocks in one region tend to be balanced by decreases in another group in another region. However, the fact that long-term climatic changes could determine major epochal increases in fish production from some stocks in some areas, and equivalent declines from other stocks and areas, merits serious consideration because the impacts at the local and regional levels are bound to be far larger. For instance, at present, large international market flows come from developing into developed areas (i.e., from the south to the north), but the oscillations in production between the North Atlantic and the Pacific Ocean are likely to result in changes to these trade flows. Such changes would have significant impacts on national and regional markets, even though the total world supply could remain stable. Changes in investments and fleet movements (and fishing agreements) are also expected to be greater than suggested by the world accumulated total landing figures.

This analysis has not considered anthropogenic climate change and its possible effects on fish production. However, as available data suggest that there is a link between fish production and climate, the need to include the effects of global warming in possible projections is clear. The results reported suggest that shifts in climate could have noticeable positive or negative effects on some, if not most, major commercial fish stocks.

One important element of the interaction between fisheries and climate is uncertainty. In this context an important policy question is how

management strategies should be formulated in order to cope with uncertainties on future climatic changes affecting fish stocks? There seems to be a worldwide consensus that a key element of long enduring resource-base human systems in a changing environment is adaptation (IPCC, 2001). Fisheries management adaptation to climate changes can be based on formal and informal arrangements. Formal policies refer to actions taken by Governments, including legislation, regulations and incentives to mandate or facilitate changes in socio-economic systems, aimed at reducing vulnerability to climate change. Informally, fishing communities have also found ways to increase their chances of success and survival in a changing environment. Community adaptive strategies include flexibility in seasonal fishing patterns, the development of networks for sharing food and other resources and intercommunity trade (Berkes and Jolly, 2001). The goal of adaptive management policies and strategies is to reduce vulnerability, and research on vulnerability of fisheries to present and future changes in climate can certainly contribute to the formulation of better adaptive policies.

Fisheries management under climatic uncertainties can also benefit from risk assessment and management procedures and the adoption of a precautionary approach (Cochrane, 2002). The risk to be assessed and managed in this particular case would be the probability that stocks will fall below minimum accepted thresholds as a result of climate and fisheries. A strategy that tighten protection of the resource at periods of low abundance and/or when it goes below a certain threshold and allows fishing to expand when abundance is high, has been suggested as an alternative to deal with highly variable resources and fisheries (MacCall, 1980; Csirke, 1984, 1987). This should provide sufficient protection from fisheries driven depletion while allowing fishing to expand to make full use of epochs of high abundance. However, this approach relies on timely and reliable information on what would happen next and the capability of managers and harvesters to adapt timely to these changes, the absence of which will only add to the underlying uncertainty. But risk management involves to a large extent finding, and taking, decisions that are more robust to the uncertainties on future climatic regimes and to lack of knowledge. A robust strategy is one that minimizes the chances

that a decision will go very wrong and that leaves room for ignorance. In this respect, it has been proposed that in many instances a robust strategy to cope with uncertainties created by climatic effects on marine fish populations is rather the adoption of a constant harvest rate rule, in which a fixed proportion of the stock is allowed to be harvested annually (Walters and Parma, 1996).

Management strategies should also allow quick adaptation in case the system does not behave as the assessment suggested without causing unnecessary economic and social disorder (Cochrane, 2002). The precautionary approach, on the other hand, sets the general principles to be adopted when taking uncertainties into account in fisheries management decisions. The precautionary approach proposes that when there are uncertainties about the productive capacity of the stocks priority should be given to conservation. One example of precautionary actions for fish stocks characterized by long-term regimes in productivity is to adopt conservative management measures and adjust investment plans considering the high fish productivity in a preceding regime as a limit. Precaution also involves avoiding changes that may not be potentially reversible and prior identification of undesirable outcomes and measures that will avoid or correct them promptly.

Lastly, the success of any management strategy to cope with climate variability hinges on information. One of the major constraints in understanding the causes of regional variations in fisheries production and forecasting future regimes is the lack of long-term data. Information about past changes and impacts also plays a fundamental role in building management institutions with the required adaptive flexibility, as expectations about future changes tend to be better understood if there is a clear parallel with past experience (IPCC, 2001). Improvements of the quantity and quality of information on fishery-climate interactions depend on better fishery monitoring schemes, the development of integrated sampling systems for physical and biological properties of the ocean, including the abundance of fish early life cycles, advances in circulation and ecosystem models, as well as collection of data on social and economic impacts of climate variability and extremes.

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D. MARINE RESOURCES TABLES

This section contains Tables D1 to D17 referred to in the regional reviews (Section B) and the global review on tunas (Chapter C1). Since these tables summarize information that is supplementary to that provided in previous sections, reference should be made to the pertaining regional or global reviews for further details and clarification regarding the fish resources in each FAO Statistical Area. Each table includes for each of the main stocks or group of species in the Area a short list of the main fishing countries, catch data for each year from 1996 to 2002 and ten-year averages from 1950 to 1999, as well as a brief annotation on their state of exploitation. Grand totals of marine capture. Marine aquaculture and total production (capture plus aquaculture) are included at the bottom of each table. Brief notes describing the criteria and symbols used in the following tables are provided below.

Catch and landings

All catches are expressed in tonnes and are rounded to the nearest thousand. The concept "nominal catch" (usually referred to as "catch" throughout the document), refers to the landings converted to live weight basis. The main sources of the catch and landing information are:
- FAO Yearbook of Fishery Statistics (catches and landings), FAO, Rome
- FAO FishStat Plus (http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp)
- FishBase (http://www.fishbase.org)
- CECAF Statistical Bulletins (for the Eastern Central Atlantic, Area 34)
- GFCM Statistical Bulletins (for the Mediterranean and Black Sea, Area 37)
- Various national and regional bulletins and reports (for various Areas)

Stock or species groups

Each table includes selected exploited or exploitable stocks or groups of species. Criteria for selection includes high volume of current or historical catches, high commercial value and high potential for development. These have been grouped by FAO ISSCAAP (International Standard Statistical Classification of Aquatic Animals and Plants) species groups using the most recent changes descriubedc below.

Some changes in the ISSCAAP grouping have been introduced in the latest version of the Yearbook of Fishery Statistics and the FAO FishStat Plus, these have been included in this review. These changes follow the recommendation of the 19th Session of the Coordinating Working Party on Fishery Statistics - CWP (Nouméa, New Caledonia, 10-13 July 2001). Accordingly, the names and composition of former groups 33, 34 and 37 of the FAO International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) have been revised as follows (the chart below better illustrate these ISSCAAP group changes):

- the species items of the former group 33 "Redfishes, basses, congers" were classified as coastal or demersal fishes and accordingly assigned to the new groups 33 "Miscellaneous coastal fishes" and 34 "Miscellaneous demersal fishes";
- the species formerly included in group 34 "Jacks, mullets, sauries" were moved to group 37, which was renamed "Miscellaneous pelagic fishes".

ISSCAAP Group changes

Code	Old ISSCAAP group	New ISSCAAP group	Species added	Species removed
33	Redfishes, basses, congers	Miscellaneous coastal fishes	Mullets & threadfins	Demersal species from group 33
34	Jacks, mullets, sauries	Miscellaneous demersal fishes	Demersal species from group 33; snoeks & cutlassfishes	All species from group 34 except lanternfishes
37	Mackerels, snoeks, cutlassfishes	Miscellaneous pelagic fishes	All species from group 34 except mullets & threadfins	Snoeks & cutlassfishes

Main fishing countries

Up to a maximum of four main fishing countries are listed for each stock or species group and countries are listed in ranking order by catch size in 2002.

State of exploitation

The state of exploitation as shown by the abbreviations below represents our best and most recent estimate of the state of the stock, its potential for increased production or requirement for stock recovery. The estimates are based on the best information available, which may include the results of peer-reviewed published reports as well as the analysis of qualitative data and information whose reliability may vary from one region to another as well as between stocks or groups of the same or of different species within the same area.

? (or blank) = Not known or uncertain. Not much information is available to make a judgment;

U = Underexploited, undeveloped or new fishery. Believed to have a significant potential for expansion in total production;

M = Moderately exploited, exploited with a low level of fishing effort. Believed to have some limited potential for expansion in total production;

F = Fully exploited. The fishery is operating at or close to an optimal yield level, with no expected room for further expansion;

O = Overexploited. The fishery is being exploited at above a level which is believed to be sustainable in the long term, with no potential room for further expansion and a higher risk of stock depletion/collapse;

D = Depleted. Catches are well below historical levels, irrespective of the amount of fishing effort exerted;

R = Recovering. Catches are again increasing after having been depleted or a collapse from a previous high.