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Environmental Indices – A Review on Climatic Variability and Potential Effects on Marine Ecosystems

by

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Abstract

A review is given which deals with recently published material on relations among fish productivity in ecosystems and environmental variables, between climate variability and the effects on marine ecosystems. The paper concludes that despite the chaotic nature of the climatic system, and the fact that climatic research may be able to predict on decadal scales, the present generation of marine scientists should start with the incorporation of environmental indices in the population model of the fishery.

Keywords: environmental variables, climate variability, effects on marine ecosystems, environmental indices, El Nino, NAO Index, ENSO, SOI Index, temperature

Introduction

In an abstract on "Population dynamics of the Shark Bay saucer scallop fishery" it is stated "that independent recruitment surveys have shown that there has been ***massive variations in the recruitment index*** *over the past 10 years. There is apparently some connection with the strength of the Leeuwin Current, but the mechanism is not known, and the connection is confounded with at least one other effect. The author* (**Joll, 1994**) *concludes that "An understanding of the environmentally-related variation in recruitment is a necessary early task in the development of any population model of the fishery."*

Various authors have tried to establish relations among fish productivity in ecosystems and environmental variables, between climate variability and the effects on marine ecosystems. There is an increasing demand for environmental information, such as an environmental index, which could be incorporated in the fishery assessment process. NAFO through its Standing Committee on Fisheries and Environment (STACFEN) initiated a discussion on how to arrive at suitable environmental indices which could be used for the annual assessment procedures performed in the Standing Committee on Fisheries Science (STACFIS).

Examples on how to achieve environmental indices are given in a paper by **Stein and Lloret (1999)** for discussion in STACFEN.

In the following a Review is presented which deals with published material relevant to the task of environmental indices. In a chapter on Conclusions the author outlines some thoughts on the usefulness of prognostics in environmental data, and points at the risks when performing an environmental prognosis.

Review

Global Scale

The El Nino-Southern Oscillation (ENSO) variability is probably the best known mechanism of global climate variability, with large effects on marine ecosystems and particularly on small pelagic populations (**Lluch-Cota et al., 1997**). However, major changes of small pelagic (abundance regimes) tend to occur on the interdecadal scale, rather than with the interannual variability normally associated to ENSO. Despite some recent research, the role of ENSO variability at determining interdecadal climate variations (climate regimes) is still a matter of controversy. The authors examine the statistical relationships between small pelagic and climate regimes and ENSO activity, and between these and indices of extratropical and solar variations over the interdecadal time scale. Climate regimes are detected within the Global Surface Air Temperature record, and within other large-coverage air temperature time series. Climate regimes seem to be global phenomena although the signal is not equally strong worldwide. A relationship is suggested between climate regimes and El Nino frequency and strength; warm (cool) regimes grossly correspond to periods of few and weak (many and strong) events. Warming (cooling) trends may be characterised as periods of low (high) Southern Oscillation Index (SOI) average values. It is also suggested that a change from one regime to another tends to occur when extreme SOI values are reached. Small pelagic regimes are defined from catch records of the main world fisheries: Japan, California, Humboldt, Benguela and Canary. A composite series (RIS) was constructed. This series is a good indicator of decadal-scale global changes since it tends to emphasise common long-term variability of the stocks while reducing the effects of the individual, year- to-year variations. Comparison between RIS and climate regimes strongly suggests global decadal variability is first evident at the boundary systems of the oceans where small pelagic stocks develop. For the relationship between the ENSO (as a tropical mechanism) and the Aleutian Low (as a component of the extratropical climate system) their results suggest that periods of relatively high solar activity tend to promote tropical-extratropical coupling; whereas independent tropical-extratropical variability tends to occur at moderate to low solar activity. Worldwide sardine growing periods (upward RIS trends) seem to occur at moderate to low solar activity. Worldwide sardine growing periods (upward RIS trends) seem to occur when the tropical and the extratropical systems tend to behave independently. Anchovy growing is probably favoured by coupled tropical-extratropical interdecadal variability.

As shown by **Tsai et al. (1997)** monthly abundance (CPUE) of larval anchovy in the coastal waters off south-western Taiwan from 1980 to 1992 (156 months) fluctuate at intervals corresponding to the 4.3- and 2.2-year cycles of the southern oscillation index (SOI). Also, CPUE is significantly correlated with sea surface temperature with a time lag of 3 months and nearly significantly to river flow with a time lag of 4 months, which in turn correlates with SOI at lags of 13-14 months (cross-correlation and transfer function analyses). The results suggest the presence of linkage between recruitment of the larvae and ENSO episodes, perhaps through oceanographic and meteorological conditions that affect coastal upwelling and river discharge. The Kuroshio Current, which is the western extension of the North Equatorial Current, may be one of the important mechanisms of ENSO’s teleconnections affecting local climate and fisheries in the western Pacific region.

Compared to earlier decades, there is a significant body of biological evidence to suggest that the carrying capacity of the Gulf of Alaska has increased since the late 1970s (**Polovina, 1996**). Changes have occurred at several trophic levels from zooplankton to at least salmon. This is possibly due to changes in the intensity of the Aleutian Low Pressure System. A comparison of zooplankton abundance in the Gulf of Alaska between 1956-1962 and 1980-1989 shows a doubling of summer zooplankton biomass, pelagic fish, and squid abundance in the latter period. Trends in North Pacific salmon production follow changes in the Aleutian Low Pressure Index from 1925-1989. Above average North Pacific salmon catches occurred during 1925-1945 and 1977-1989, when the Aleutian Low Pressure System was more intense than average. Below average salmon catches occurred during 1946-76 when the Aleutian Low was weaker than average.

Based on recent studies which highlight the dominating influence of the North Atlantic Oscillation (NAO) on climatic changes in the North Atlantic Ocean, and their potential influences on biotic processes in the ocean, **Stein et al. (1998)** analyse existing time series of recruitment of cod (*Gadus morhua*) off Greenland, air temperatures of Nuuk/West Greenland, subsurface ocean temperature on Fyllas Bank, and the winter (December to February) NAO Index. As a first objective the paper outlines a causal nexus from NAO to recruitment of cod. It is shown how the increasing complexity of the system when moving from the NAO Index to the water temperature and recruitment through the air temperature, might complicate the existence of a direct relationship between the first and the last step of the system, which leads to a decreasing correlation from the top (NAO Index) to the bottom (recruitment). The second objective of the paper is to reveal by means of the example of Greenland cod recruitment, water temperatures in June on Fyllas Bank, air temperatures at West Greenland, and the winter NAO Index that a causal nexus can explain how Environmental Variability Effects (EVE) act on marine fisheries. Future fisheries management considerations should realise that the EVE aspect has to be incorporated in models and management decisions.

Faure and Cury (1998) analyse the relations among fish productivity and five environmental variables for eleven upwelling areas of the world. Three ‘fish catch productivity’ indices, calculated from fish catch statistics, are used as surrogates for fish productivity in the ecosystems. Five environmental parameters are considered in each upwelling areas: coastal upwelling and turbulence indices, sea surface temperature, continental shelf surface and length. On its own, the size of the ecosystem does not explain the observed differences of the pelagic fish productivity indices. Using non-parametric regression methods, it is shown that a combination of several environmental factors is required for high fish productivity. These optimal conditions are a high upwelling index (around 1.3 $m^3sec^{-1}m^{-1}$), a moderate turbulence (around 200-250 m^3sec^3), a medium sea surface temperature (15-16°C) and a relatively large continental shelf (around 100 000 km^2). The Peruvian ecosystem is the only system which combines all of these environmental conditions.

Regional Scale

Pink salmon (*Oncorhynchus gorbuscha*) harvests during 1960-1992 are positively correlated with both average winter air temperatures and brood year escapements (**Hofmeister, 1994**). Average winter air temperatures in Southeast Alaska are cyclic and linked to the sea surface temperature cycle in the Gulf of Alaska. The 18.6-year lunar cycle, with its associated tidal currents, has been implicated in high latitude sea temperature cycles. The peak historical harvest period of the late 1930s and early 1940s occurred when the winter temperature cycle was at its minimum. The population crash which started after 1941 and continued through 1960 was attributed to inadequate brood year escapement levels. The population recovery of the early 1980s to early 1990s was attributed to both improving environmental conditions, and increased escapement levels. If escapements are maintained near their current level (i.e. an index of 12 to 13 million), the harvest will probably become cyclic and linked to the winter air temperature cycle. Maintaining adequate escapements is also expected to result in average harvest levels well above those which occurred during the last two lows in the winter air temperature cycle.

Analysing the variation in length-at-ages 4 to 5 years for Atlantic cod off Greenland **Rätz et al. (1998)** reveal significant declines in size for these age groups since the mid 1950s by 10 and 5 cm, respectively. The growth models considered temperature, fishing mortality and stock abundance effects, all of them expressed as means over the life span of individual year classes. The positive temperature and negative fishing mortality effects were found to dominate the variation in length-at-age. However, the analyses did not indicate a negative effect of stock density on cod growth. During the period 1956-89, the number of recruits at age 3 years were identified to be significantly correlated with the spawning stock biomass and June water temperature on top of Fyllas Bank (West Greenland). Both factors positively affected the number of offsprings and explained 51% of the observed variation in recruitment.

An analysis of the growth of immature North-east Arctic cod (*Gadus morhua*) in the period 1953 to 1989 is presented by **Joergensen (1992)**. The paper addresses in particular the long-term changes and attempts to relate these to variations in the ratio of capelin *(Mallotus villosus*) to cod stock abundance (an index of food availability) and temperature fluctuations. The amplitude of the short-term variations was of the order 10-15 cm. Growth in length of cod is found to be positively related to increasing ratio of capelin to cod stock abundance and also to increasing water temperature. Clear geographical differences in length-at-age of cod are observed within the Barents Sea. The estimation of mean size-at-age is therefore critically dependent on the sampling strategy.

Cod (*Gadus morhua*) is the only fish species of commercial importance in the Baltic which is influenced by the environmental changes caused by inflows or lack of inflows, because this species reproduces below the halocline with pelagic eggs (**Bagge, 1993**). Other important species, herring (*Clupea harengus*) sprat (*Sprattus sprattus*) and flounder (*Platichthys flesus*) reproduce above the halocline as well or in freshwater. If the yearclass strength of cod is taken as an index of success of reproduction a significant positive correlation should be expected between that and the salinity and oxygen content below the halocline.

Oceanographic conditions in spring and summer, caused by northerly-easterly winds of medium and low intensity, in the Bay of Biscay seem to induce good levels of recruitment to the anchovy (*Engraulis encrasicolus*) population (**Borja et al., 1996**). This wind regime produces upwelling conditions with, generally, low degrees of turbulence. Indices of upwelling and turbulence were built and proved significantly correlated with an index of annual recruitment of anchovy ($p<0.0001$). Both physical parameters explain about 70% of the variance in the index of recruitment of the Bay of Biscay anchovy. The likely explanations for this relationship are outlined and discussed in the light of the current hypotheses about the processes determining recruitment of marine populations. Enhancement of the productivity and increased availability of food to the early life history stages of anchovy seem to be the main consequence of the prevalence of weak upwelling conditions in this area during spring.

Yanez et al. (1992) use multiple regression analysis to explain the observed variability of the abundance index and catch of the fishery for common sardine (*Clupea bentincki*) and anchovy (*Engraulis ringens*) between 1965 and 1976, and for the fishery for jack mackerel (*Trachurus murphyi*) between 1974 and 1989 in the area off Talcahuano, Chile (35-38 °S). The multiple regression model for the first case includes fishing effort, sea surface temperature and turbulence index as explanatory variables ($r^2 = 0.92$). However, for the jack mackerel, sea level, turbulence index, air temperature and fishing effort are the predictive variables, explaining 92% of the observed fluctuations in catch and abundance.

Yanez et al. (1998) analyse Anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) landings in the north of Chile and in Peru between 1950 and 1993. Abundance variations of both species are expressed as catch per unit effort (CPUE), and compared with VPA (Virtual Population Analysis) estimates. Environmental fluctuations are analysed through historical series of the Southern Oscillation Index (SOI), sea surface temperatures (SST), and the upwelling and turbulence indices. A global production model is fitted to data from the anchovy fishery of the north of Chile and in Peru from 1957 to 1977. The model explains variations of CPUE as a function of fishing effort and of SST, included as a linear subfunction of carrying capacity (B infinity). A similar model for the sardine fishery is fitted to data from the north of Chile from 1975 to 1992. The latter includes CPUE, fishing effort, and SST as a quadratic subfunction of B infinity as explanatory variables. It is concluded that both resources were intensively exploited and affected by environmental changes that impacted surplus production. Anchovy develops better in a relatively cold environment; meanwhile sardine shows a clear preference for warm periods, but not as extreme as the El Nino 1982-83.

The level of puerulus settlement has proven to be a reliable predictor of the recruitment to the western rock lobster (*Panulirus cygnus*) fishery three and four years later (**Caputi et al., 1993**). It is generally accepted that the early larval stages are moved offshore by wind-driven surface currents. Previous studies have shown that coastal sea level, used as an indicator of the strength of the Leeuwin Current flowing down the west coast of Australia, was positively related to the level of puerulus settling on the inshore reefs after a 9- to 11-month larval life. In this paper a significant relationship is also demonstrated between winter/spring storms, which are usually associated with onshore westerly winds, and the level of puerulus settlement (multiple correlation of 0.83, $r^2 = 0.68$, $n = 22$). Rainfall from coastal localities is used as an index of the storms. The residuals from this relationship show a significant positive autocorrelation. The autocorrelation was incorporated into the relationship by using time series analysis with a transfer function model and a first-order autocorrelation ($r^2 = 0.76$). The possible relationship between storms and the Leeuwin Current and their effect on the puerulus settlement are considered, and the potential for the environmental variables to bias or obscure the spawning stock recruitment relationship is discussed.

Conclusions

From recent literature the conclusion may be drawn that understanding of the environmentally-related variation in recruitment is vital for the development of any population model of the fishery which includes environmental indices. Depending on the space and time scales these models must include variability on the interdecadal scale, and on the interannual scale. It is shown that warm (cool) regimes grossly correspond to periods of few and weak (many and strong) events. Air pressure indices like the North Atlantic Oscillation Index (NAO) or the Southern Oscillation Index (SOI) average values may indicate warming (cooling) trends during periods of low (high) index. These warm (cool) regimes grossly correspond to periods of few and weak (many and strong) events. Monthly abundance (CPUE) of larval anchovy in the coastal waters off south-western Taiwan fluctuate at intervals corresponding to the 4.3- and 2.2-year cycles of the southern oscillation index (SOI). Also, CPUE seems to be significantly correlated with sea surface temperature with a time lag of 3 months and nearly significantly to river flow with a time lag of 4 months, which in turn correlated with SOI at lags of 13-14 months (cross-correlation and transfer function analyses).

On the regional scale there is indication that above average North Pacific salmon catches occurred during times when the Aleutian Low Pressure System was more intense than average. Below average salmon catches occurred when the Aleutian Low was weaker than average. A direct relationship from NAO to recruitment of cod off West Greenland cannot be established. There is evidently a systemic decreasing correlation from the top (NAO Index) to the bottom (recruitment). For upwelling areas it is documented that a high upwelling index, a moderate turbulence, a medium sea surface temperature and a relatively large continental shelf favour high fish productivity. The Peruvian ecosystem is the only system which combines all of these environmental conditions. The number of West Greenland cod recruits at age 3 years are identified to be significantly correlated with the spawning stock biomass and June water temperature on top of Fyllas Bank (West Greenland). Both factors positively affect the number of offsprings and explain 51% of the observed variation in recruitment. Growth in length of North-east Arctic cod is found to be positively related to increasing ratio of capelin to cod stock abundance and also to increasing water temperature. Yearclass strength of cod in the Baltic Sea is taken as an index of success of reproduction. A significant positive correlation is expected between that and the salinity and oxygen content below the halocline. The wind regime in the Bay of Biscay produces upwelling conditions with, generally, low degrees of turbulence. Indices of upwelling and turbulence are built and proved significantly correlated with an index of annual recruitment of anchovy ($p<0.0001$). Both physical parameters explain about 70% of the variance in the index of recruitment of the Bay of Biscay anchovy. A multiple regression model including fishing effort, sea surface temperature and turbulence index explains 92% in the variation of the sardine catch and abundance off Talcahuano, Chile. However, when using sea level, turbulence index, air temperature and fishing effort as predictive variables for jack mackerel, 92% of the observed fluctuations in catch and abundance can be explained.

With all these promising results in mind one should not forget that climate prediction with coupled models is at a rather early stage now. It is comparable to the status of the numerical weather prediction in the late 1950s (**Latif, pers. comm**.). The two most important components in the climate prediction are the oceans and the atmosphere. Fourteen days atmosphere prediction is the present boundary.

We have to consider the time scales for the variability in the deep oceans ($1 – 10^2$ years), for the mixed layer (10^{-2} – 1 year), and the ice sheets ($10^3 – 10^6$ years).

We know that the El Nino phenomenon occurs about every four years as a 4-5°K anomaly in the sea surface temperatures off South America.

We know that there are El Nino induced teleconnections within the hemispheres, e.g. the Pacific/Indian Ocean teleconnection.

We know about a –0.6 to –0.7 correlation between the Northern and Southern hemisphere (**Latif, pers. comm**.).
At present it is possible to predict changes effected by El Nino. However, due to the chaotic nature of the climatic system we will never get a 100% information, we will get probabilities. And, to finally cite again from the climatic research: “We may be able to predict on decadal scales”(**Latif, pers. comm**.).

Nevertheless, our generation of marine scientists should start with the incorporation of environmental indices in the population model of the fishery since all our recent discussion has emphasised that *“An understanding of the environmentally-related variation in recruitment is a necessary early task in the development of any population model of the fishery.”*

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