COMPARISON OF THE IVOIRO-GHANAIAN FISHERY WITH OTHER EXPLOITED UPWELLING SYSTEMS OF THE WORLD

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Abstract :

A comparison of the Ivoiro-Ghanaian fishery with other exploited upwelling systems of the world is presented. The Ivoiro-Ghanaian continental shelf is fairly small but has a similar «fish productivity» compared to other upwelling systems (the exception is the Humbolt current). Crashes and explosions are inherent to most large or small pelagic fish populations living in Ekman-type upwelling or other types of oceanographic environment. Crashes are sudden and recoveries are not predictable in time, neither in strength. In Côte d'Ivoire-Ghana the stock level of one of the two sardinella species (*S. aurita*) collapsed and remained at a very low abundance level, it lasted during a rather short time period compared to other pelagic fish resources that are known to have collapsed. Like for the other pelagic species the recruitment of *S. aurita* off Côte d'Ivoire-Ghana appears to be strongly affected by environmental fluctuations. Species composition of the catch is frequently changing in pelagic fisheries. The sustainability of the ecological system in Côte d'Ivoire-Ghana, as well as in other upwelling areas, has a dynamical dimension and adaptive management should receive more attention when considering unstable resources. Because of its convenient small size, of the originality of its functioning, the Côte d'Ivoire-Ghana coastal zone should be considered as a model for further case studies on ecosystem analysis and adaptive management.

Résumé:

Ce document expose une comparaison de la pêcherie ivoiro-ghanéenne avec d'autres pêcheries d'upwelling dans le monde. Le plateau continental ivoiro-ghanéen est relativement petit mais a une productivité en poissons similaire à celle des autres systèmes d'upwelling (à l'exception du courant de Humbolt). Les effondrements et les explosions de population sont inhérents à la plupart des populations de petits et grands poissons pélagiques vivant dans des upwellings de type d'Eckman ou d'autres types d'environnement océanique. Les effondrements sont soudains et les récupérations ne sont pas prévisibles dans le temps et en intensité. En Côte d'Ivoire-Ghana l'abondance du stock d'une des espèces de sardinelles (S. aurita) s'était effondrée et est restée a un très faible niveau d'abondance; cette situation a duré pendant un faible laps de temps comparé aux autres ressources pélagiques dont on connaît l'effondrement. Comme pour les autres espèces pélagiques, le recrutement de S. aurita au large de la Côte d'Ivoire-Ghana semble être fortement influencé par les fluctuations de l'environnement. La composition par espèces des captures change fréquemment dans les pêcheries de pélagiques. La stabilité du système écologique côtier de la Côte d'Ivoire-Ghana, comme pour les autres zones d'upwelling, a une dimension dynamique et une gestion adaptative devrait être particulièrement envisagée pour ces ressources considérées comme instables. De par sa petite taille, ce qui est commode, et l'originalité de son fonctionnement, la zone côtière de Côte d'Ivoire-Ghana devrait être considérée comme un modèle pour de futures études de cas d'analyse du fonctionnement d'un écosystème et de gestion adaptative.

1. Learning from the past

Ecologists have been working for about forty to fifty years on marine ecosystems collecting biological and environmental data and we are now in a good position to learn from changes, i.e. to learn from quantitative changes in the catch, but also from qualitative changes, that is the species composition of the landings. Population crashes and explosions are quite frequent in coastal pelagic ecosystems. Three of the most important pelagic fish stocks in the world are well known for their long term instability: the Japanese sardine (*Sardinops melanosticta*), the Pacific sardine (*Sardinops sagax*) and the Peruvian and Chilean anchoveta (*Engraulis ringens*) (Troadec et al 1980; Sharp and Csirke 1983). The threat of fishing may also be real for pelagic fish stocks and better management strategies need to be considered (Beverton 1990). Instability does not only occur in large populations of pelagic fish but also in small ones. Thus, one of the two species of sardinellas (*S. Aurita*) that is intensively exploited in Ghana and in Côte d'Ivoire collapsed in 1973, and a dramatic recovery of the biomass recently occurred (this volume). To identify factors that may play an important role in population dynamics is a first step in any ecological analysis, then to confront these results with others, found in different upwelling systems, is a way to generalize patterns and processes. The comparative method is a powerful tool that may help to identify causal mechanisms and responses in population dynamics (Mayr 1981; Bakun 1994). First, a brief review of the world pelagic fisheries is proposed to stress the importance of pelagic fish instability in the Ivoiro-Ghanaian ecosystem by comparison to others. Then some factors that affect pelagic fish productivity in upwelling systems are discussed to emphasize similarities and particularities that may exist in the Ivoiro-Ghanaian ecosystem. Lastly, considerations are put forward to further develop research on adaptive management for pelagic fish resources in Côte d'Ivoire and Ghana.

2. Pelagic fisheries: Unstable resources in a limited world.

During the last four decades the world marine resources have been intensively exploited. The world total catch was 30 millions of metrictons in the fifties, now 100 millions of metrictons are fished every year (fig.1). The recent collapse of the Japanese sardine (*Sardinops melanostictus*) and of the Chilean sardine (*Sardinops sagax*) adds little hopes to any possible future increase for the marine fish catch. Marine fish catch always represents a large percentage, around 75% of the total world catch (fig.1). The pelagic fish catch (sardine, anchovies, herrings, mackerels) represents half of the marine fish catch: they also are of great importance for the world fishing industries (Durand this volume). A sustained trend is observed in the catch (fig.1) which is mainly due to an always increasing fishing effort. However, fluctuations are observed from one year to another that sometimes represent several million tons. When removing the global trend by calculating the first differences (catch at time t minus catch at time t-1) it appears that, from one year to another, the variability of the marine world fish catch is essentially due to the clupeoids (i.e., sardines and anchovies) (fig. 2). Forty percent of the marine fish are caught in upwelling areas. When considering the eleven most important species for the world catch, nine of them are pelagics and six of them are clupeoids (fig. 3). The genus *Sardina* and *Sardinops* are well represented but the genus*Sardinella* does not appear in this list of species as they are not fished in great abundance worldwide. Even at a world level, species composition can rapidly change. For example, the anchovy (*Engraulis ringens*) was very abundant in the world catch in 1974, and sardinops (*Sardinops melanostictus*) contributed to just a few percent; in 1984, i.e., ten years later, the opposite was observed (fig. 3).

3. The Ivoiro-Ghanaian fishery and fishery and main pelagic fisheries of the World.

2.1 Collapse: How long will it last ?

During the last decades the main coastal pelagic fisheries presented drastic fluctuations (see e.g., Sharp and Csirke 1983; Pauly and Tsukayama 1987; Wyatt and Larrañeta 1988; Cury and Roy 1991; Kawasaki et al. 1991; Le Loeuff et al. 1993). The Peruvian anchoveta was the most important fishery in the world. In the sixties, the landings were between 8 and 12 million tons. In 1973 the stock collapsed. It remains at a very low level between 1977 and 1987 and it seems that the stock is now recovering at a lower level to what it was in the sixties. Since 1977, the Sardinops population has dramatically increased and now between 2 and 3 million tons are fished every year (fig. 4) (Pauly and Tsukayama 1987). At a different scale, similar patterns were observed for the Chilean fishery. One million ton of anchoveta was caught in the sixties, then the stock collapsed in the 70"s and recently reappeared. An important increase in the sardine and trachurus populations is observed since 1977 (Serra 1991) (fig. 5). The sardine fishery was very prosperous in the 30 and 40"s in California with an annual catch between 4 to 5 hundred thousand tons. The stock collapsed in the 50"s and the sardine never reappeared despite a closure of the fishery (MacCall, 1986) (fig. 6). The same pattern has been observed for the anchovy that was quite abundant in the 70"s and has disappeared during the recent period. Similar pattern was observed for the sardine off Namibia that collapsed in 1978 and never recovered (Crawford et al. 1987) (fig. 7). Collapses and recoveries are not only observed in upwelling areas. After an increase in the fleet activity during the twenties, the Japanese fishery landed around 1.5 millions tons of sardines around Japan during the thirties, after 1940 the stock collapsed. In 1966, fisheries scientists said «there are no more sardines around Japan», and during 27 years the catch remained at a very low level . Recently the stock recovered very rapidly. During the 80"s they caught between 3 and 4 million tons. According to recent statistics the stock is collapsing again (in 1992 they fished less than 2 million tons) (Kondo 1980, 1991; Kawasaki et al 1991) (fig. 8). Drastic changes were also experienced in the pelagic fisheries off Côte d'Ivoire and Ghana: a sudden collapse in 1973 of the *Sardinella aurita* stock, then followed by a sustained recovery in the mid-seventies (Koranteng 1991; Binet et al. 1991). The total pelagic fish catch in Ghana and Côte d'Ivoire is much higher to what it was during the beginning of the fishery, despite a fishing effort that decreased (in Côte d'Ivoire) (fig. 9, 10). Collapses are not always observed when considering a long time period. For example none of the pelagic fish species exploited off West India (Longhurst and Wooster 1990), Morocco (Orbi et al. 1991) or Spain and Portugal (Dickson et al. 1988) disappeared completely from the landings, even if important fluctuations were observed in those fisheries (fig. 11, 12, 13). *Sardinella aurita*, a species that is also fished in Senegal, never collapsed since the beginning of the fishery in the sixties (fig. 14).

After several decades of strong fishing activities, many pelagic fisheries have experienced a collapse. Most of the time this was the dominant pelagic species that collapsed and the number of years it lasted was highly variable. When considering the examples cited above, it varies from a few years (e.g., *Sardinella aurita* in Côte d'Ivoire and Ghana) to several decades (e.g., *S. sagax* , in California) (fig. 15). It is noticeable that the *Sardinella aurita* in Côte d'Ivoire and Ghana remained at a very low level during a rather short time period (3 years) compared to other pelagic fish resources that collapsed (fig. 15). When a stock will recover, and how much will it recover, remains a puzzling question (Cury 1988, 1994).

3.2 Size of the continental shelf: more space = more fish?

Many studies have recognized the importance of environmental factors that may account for fluctuations in the Sardinellas population off Côte d'ivoire and Ghana (ORSTOM/FRU 1976; Cury and Roy 1987, 1989; Laloë 1988; Fréon 1991; Binet et al. 1991; Binet et Marchal 1993; Binet et Servain 1993; Binet this volume; Pezennec et Bard 1992; Pezennec this volume). One question that is not addressed in these studies is the relative fish productivity of the Ivoiro-Ghanaian ecosystem by comparison to the other ecosystems. The surface of the continental shelf is an important factor as one commonly expects larger biomasses on wider continental shelves. To evaluate the differences that may exist between the Ivoiro-Ghanaian ecosystem with the others; the size of the continental shelf was measured for each ecosystem by calculating the surface between the coast line and the 200m isobath.

The Ivoiro-Ghanaian continental shelf appears to be fairly small compared to the South African, American, West African or the West-Indian continental shelf (fig. 16). To get a measurement of the «productivity» for these ecosystems, the average catch for each zone was calculated during the period of high exploitation rates (i.e. ,when the fishery was well established); then, this average catch was divided by the surface of the continental in order to obtain an index of «fish productivity» (fig. 17). The most productive fishing zone upwelling appears to be the South American upwelling area (the Humbolt current) with a ratio of 38. For all the other upwelling areas, the fleet were able to fish an average of one to four tons of pelagic fish per km^2 per year. Considering this range of values the Côte d'Ivoire-Ghana appears to be a fairly productive fishing zone with a ratio of two tons per km^2 per year (fig. 17).

Thus, more space does not necessarily mean more fish and the best example is the Peruvian and Chilean ecosystem where huge biomass of pelagics are to be found on a rather small continental shelf. Other factors limit the productivity of fish in Côte d'Ivoire and Ghana as well as in other upwelling systems.

3.3 Upwelling and Wind as limiting factors for productivity ?

The impact of the environment on larval survival is considered as a key factor on the recruitment process and consequently in the total abundance of a population. Many theories have proposed explanatory factors in order to qualify the impact of the environment on the recruitment success. In the «stability hypothesis» Lasker (1975) showed that dynamic physical processes, like the effects of turbulence, are responsible of larval mortality during «critical periods» of the life history of the fish. In the «match-mismatch» hypothesis Cushing (1990) formulated that the annual production of fish larvae match or mismatch to the production of their food. Using a comparative approach of pelagic fish reproductive strategies in upwelling areas, Parrish *et al.* (1981) found a detrimental effect of the Ekman transport for larvae survival. This «offshore transport hypothesis» has been generalized by Sinclair (1988) in the «member/vagrant» theory where the importance of spatial scale constraints of the life cycle of the population and of the dispersive characteristics of the population's geographical infrastructure are developed. These theories clearly conduct to admit that there should be two limiting factors in the upwelling areas: a trophic factor like food availability for larval survival; hydrodynamic factors like wind generated turbulence or offshore transport. Some hypotheses on the effect of the upwelling or the current intensity have been proposed to better understand drastic changes that were observed in the *S aurita* population off Côte d'Ivoire and Ghana (see Binet for a review, this volume).

For pelagic fish populations the theoretical relations between recruitment success and upwelling intensity should be expected to be dome shaped by considering two limiting factors (Cury and Roy 1989) (fig. 18). On the left side of the curve wind mixing is weak and the limiting factor is the production of food due to the low intensity of the upwelling. On the right side of the curve, the upwelling is strong and turbulence or offshore transport is then the limiting factor. It consequently defines an «optimal environmental window» for moderate upwellings where the effects of the limiting factors are minimized and the recruitment is maximum (fig. 18). This relationship between the environment and the recruitment is nonlinear. We are in a good position because we have ecological time series of several decades but we also are in a good position to analyze our data as new statistical techniques are available that allow to explore nonlinearities between data sets (Cury et al. 1994). Statistical analyses were performed for several species in different upwelling systems: sardine and anchovy in California, anchovy in Peru, sardine in Morocco, and sardinellas in Senegal (Cury and Roy, 1989; Cury et al. 1994). The empirical transformations of a multiple non-linear regression model between a recruitment index as a response variable and using upwelling index and adult biomass as predictor variables were calculated (fig. 18). The percentage of variance that is explained by the upwelling index or the wind index represents approximately 20% to 25% of the variance in the recruitment index. The effect of the upwelling appears to be dome-shaped suggesting that upwelling can be either beneficial or detrimental, depending on its intensity (Cury and Roy, 1989). It also is in good agreement with the theoretical optimal environmental window. For the sardinellas off Ghana and Ivory-Coast recruitment data are not available but a previous analysis using the c.p.u.e. (catch per unit of effort) as a recruitment index was performed (Cury and Roy 1989). The form of the relationship between the c.p.u.e. and SST (Sea Surface Temperature) one year earlier appears to be linear and suggests that stronger upwelling will produce more recruits (fig. 19). According to the theoretical relationship it suggests that the turbulence are never strong enough to have a detrimental effect on the recruitment. In a recent analysis, Pezennec and Bard (1992) confirm the importance of the minor upwelling season for the recruitment success. As upwelling is increasing as a whole in time and space, and as the wind intensity never reaches values greater than 5-6m/s, the recruitment and the upwelling intensity appears to be positively correlated (fig. 19). It suggests that in Côte d'Ivoire - Ghana the limiting factor is food availability; thus, when the minor or the major upwellings increase in strength or in duration (Pezennec and Bard 1992; Pezennec, this volume), so does the recruitment.

3.4 Management of uncertainty using a «groping strategy» ?

Environment, fish population, fishermen and markets are all part of the fisheries. These components interact and change through time. Fisheries are changing sometimes very slowly and sometimes drastically. A fishery is functioning like a kaleidoscope; a small change in one of its component will produce a new landscape of the same components arranged in a new way (i.e., a new state of the system). Sometimes this new landscape looks like the previous one; patterns are quite similar, and sometimes they have nothing to do with the previous one. Thus, dramatic fluctuations as well as species composition changes have been observed in most pelagic fisheries during the last decades. Pelagic fish stocks are also good examples of renewable resources where unexpected and drastic changes may appear very rapidly.

Learning from the past is perhaps the most probing way to avoid errors. And we are now in a good situation for learning from the past if managers, as well as scientists, learn from change (Holling 1978). We have good reasons to think that there are a lot of different factors which can drag a fishery system to a collapse or to a recovery. Unexpected events do play an important role when considering year-to-year fluctuations in pelagic fisheries or longer time periods that still are of interest for fisheries management. The question «what should have been done to avoid a pelagic fish collapse (i.e. the Peruvian anchoveta) ?» will receive many different and incompatible (in term of management) answers according to a fishery biologist, a fisherman, a fishery manager or a multinational company (Glantz and Thompson 1981; Glantz 1992). Trying to predict what will happen next year to the stock level is a great source of confusion. Exploring possible changes of a dynamical system and alternatives in management appears to be more creative (Allen and McGlade 1986, 1987, 1989). The semi-industrial fishery in Côte d'Ivoire as well as the small scale fisheries in Ghana were able to maintain their activities even through major ecological changes that appeared during the last thirty years. By their adaptive capacity they were able to face various dynamical constraints (Chaboud and Dème 1991). Success or failure may teach us the way to better manage fisheries. Thus, both the semi-industrial and the small scale fisheries developed adaptive and innovative strategies in Côte d'Ivoire and Ghana that may help us in defining future viable management strategies. Renewable resources are constantly changing and evolving (Cury 1993; Stokes et al. 1993). Management should try to consider more closely what has been done and better take into account the unexpected events, the surprises and the changes that are inevitable (Brewer 1983; Walters and Holling 1990). And to use a «groping strategy» by developing adaptive strategies will be certainly full of new scientific and management challenges. A first step will consist in analyzing the adaptive strategies that already exist in some fisheries and to explore the degree of adaptability of the industrial and small scale fisheries facing changes. Pelagic fish stocks are exploited by small scale and semi-industrial fisheries in Côte d'Ivoire and Ghana. Their relative small size (e.g., the semi-industrial fleet is composed of only twenty boats) and their spatial dynamics (e.g., all the semi-industrial catch are landed in Abidjan) allow to perform scientific studies with limited means. They also should receive more attention from the scientists who are working on how to develop management strategies for unstable resources.

4. Conclusion :

The Côte d'Ivoire-Ghana as a model for upwelling ecosystem analysis and adaptive management Studies.

Ivoirian and Ghanaian pelagic fisheries have fairly similar patterns to most other pelagic resources living in Ekman or other types of upwellings. Thus, like many other pelagic species, the *S. aurita* population collapsed and recovered at an unexpected biomass level while other pelagic stocks did not exhibit great fluctuations. Ecologist have good reasons to believe that environmental factors do play an important role in pelagic fish variability, however it is still difficult to know why one species will exhibit strong fluctuations while the sibling species will not (this is the case for the *S .aurita* and *S. maderensis*) (Cury and Fontana 1988). To examine drastic ecological changes in several ecosystems or different adaptive strategies developed by the species and to compare factors that play a role in fish stock dynamics is a way to improve our knowledge on ecosystem dynamics. Many unsolved questions may be answered by confronting ecological results from different upwelling areas. Comparative method has been identified as a key component of many international programs research strategy (Bakun 1986). Because of their importance for fisheries, large marine ecosystems are intensively studied (Sherman et al. 1993). However temporally and spatially aggregated scales limit the ability to sort out the types of interactions that are involved in temporal and spatial dynamics. To track a specific pattern or to identify a process may sometimes be easier by considering small marine ecosystems. Many environmental, biological, ecological and socio-economical data have been collected in Côte d'Ivoire and Ghana and many multidisciplinary studies were performed that led to propose testable hypotheses. For example, the role of retention area and their importance for pelagic fish population dynamics should be explored by considering the spatial heterogeneity in the Ivoiro-Ghanaian ecosystem and by defining adequate operational field studies. Because of its convenient small size, of the originality of its functioning, the Côte d'Ivoire-Ghana upwelling system should receive more attention from the international scientific community and be considered as a model for further studies on ecosystem analysis and adaptive management.

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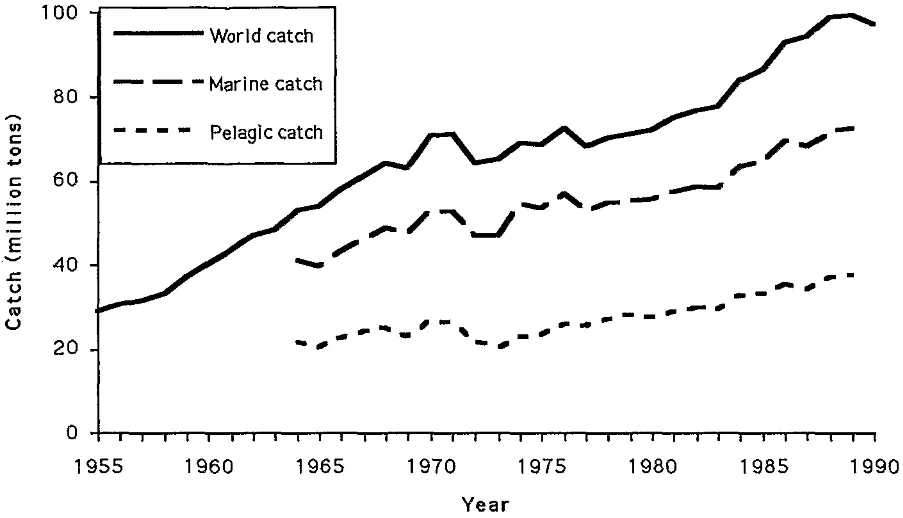

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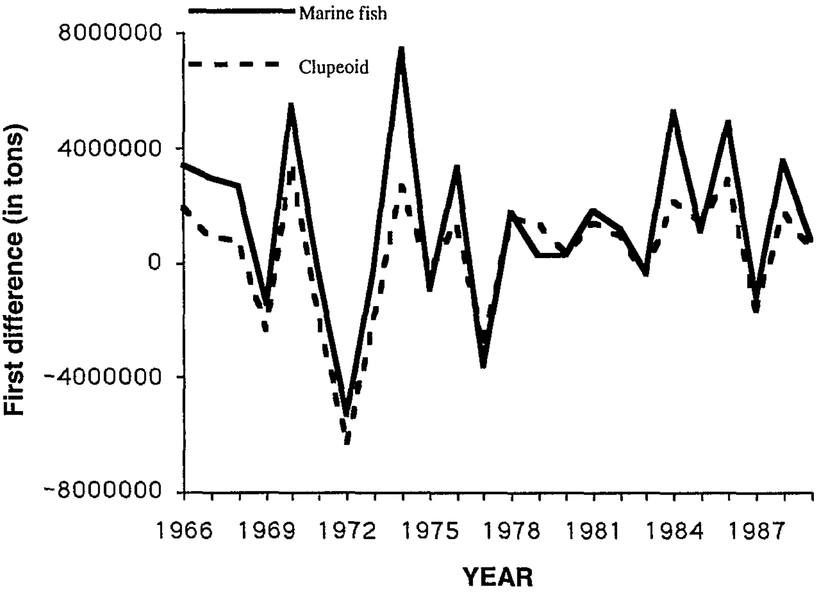

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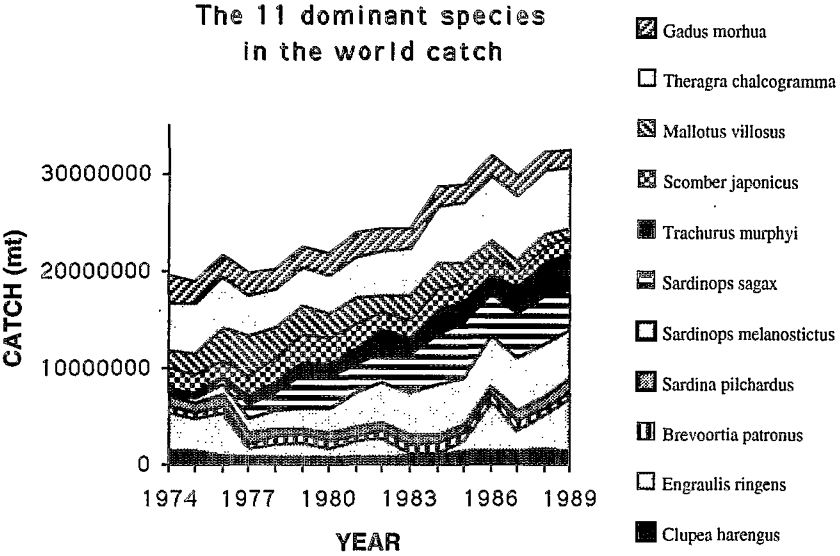

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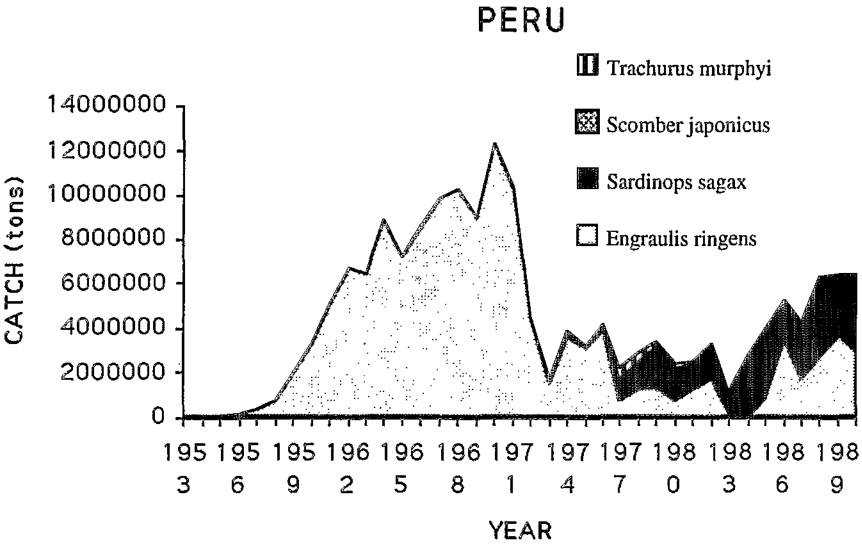

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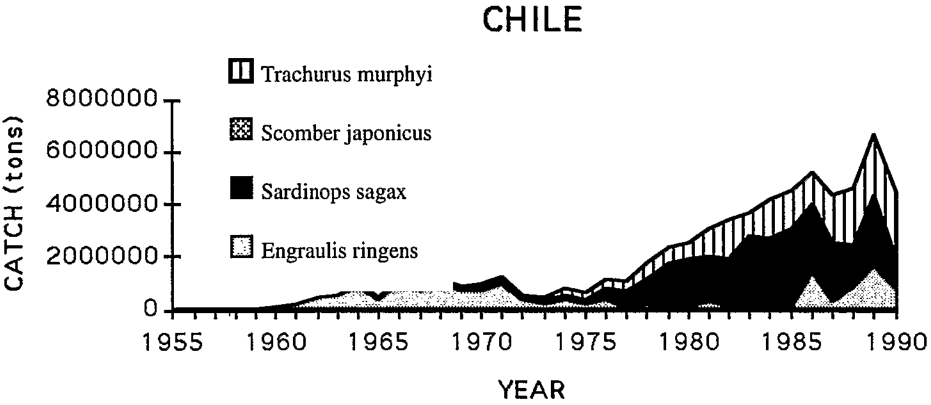

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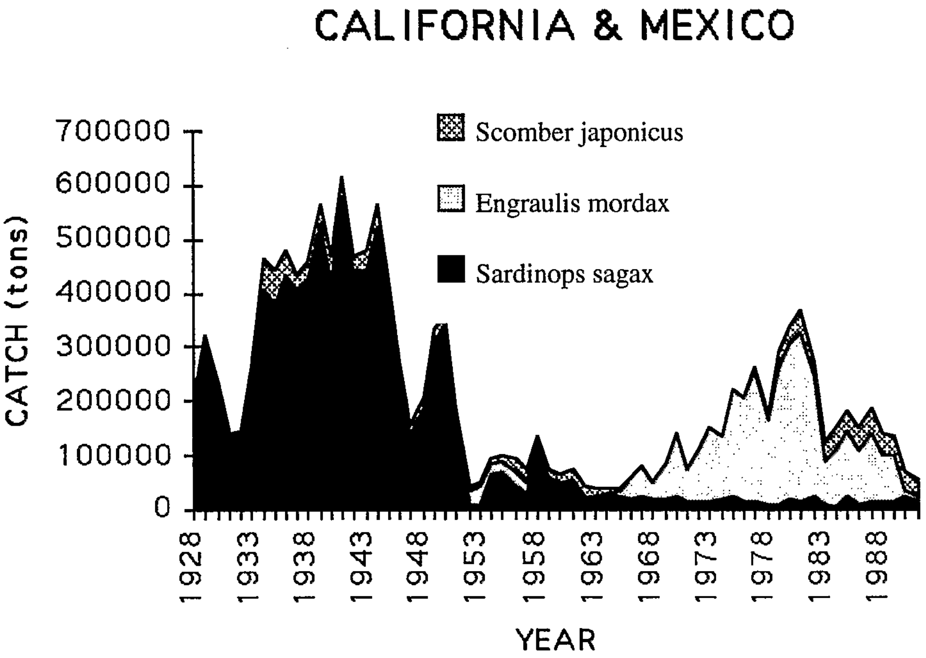

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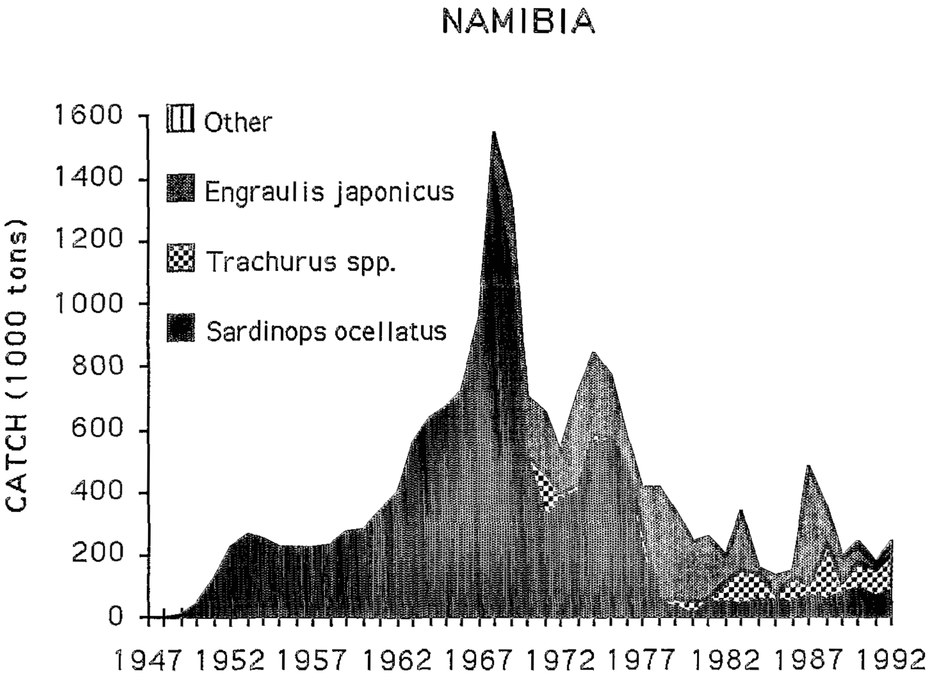

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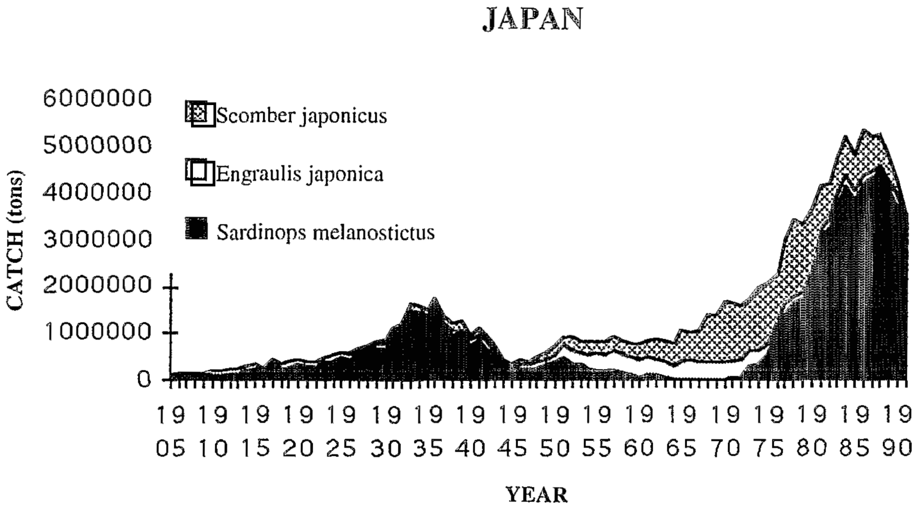

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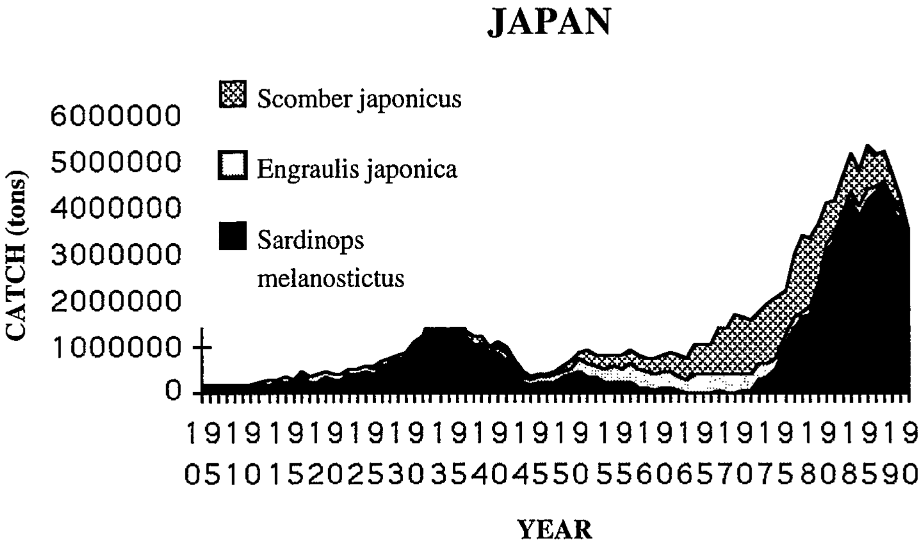

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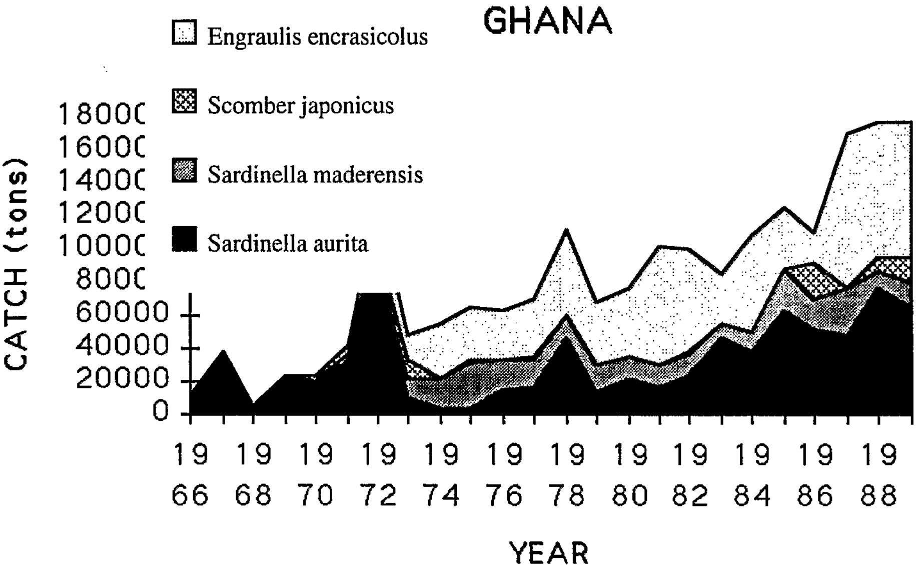

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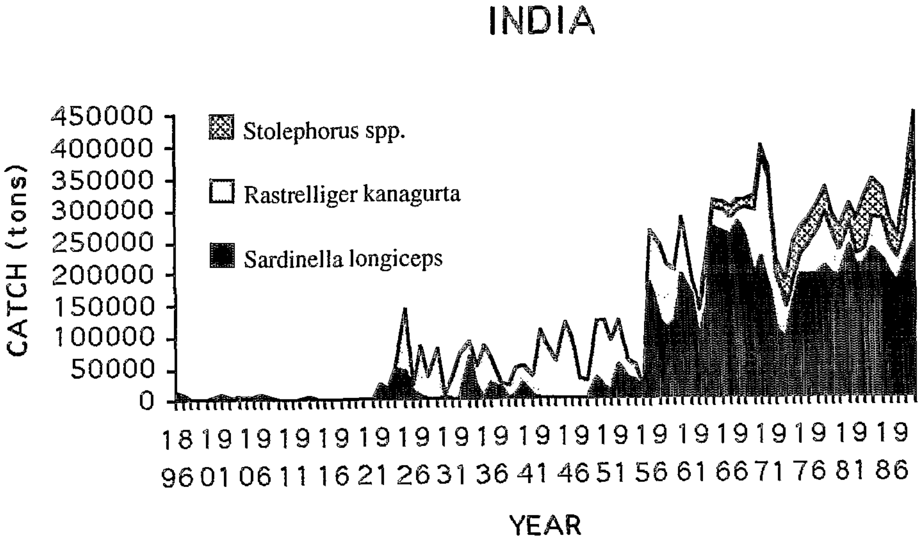

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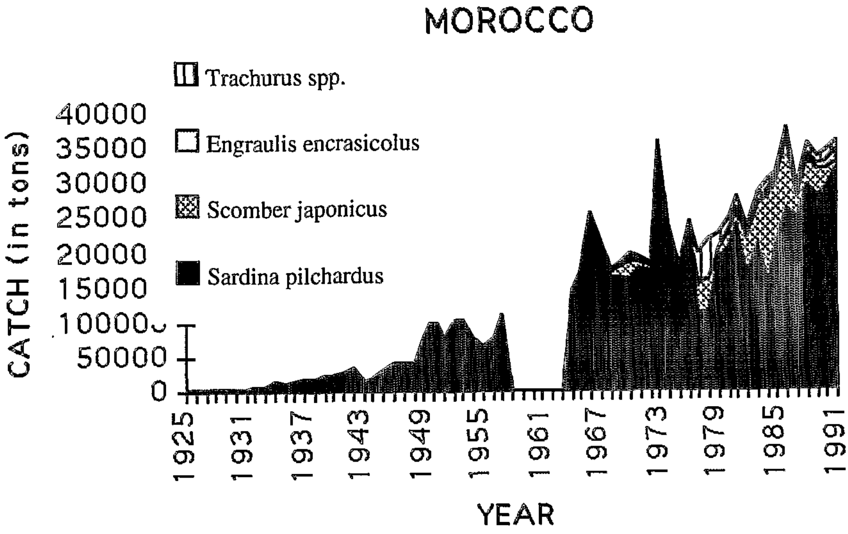

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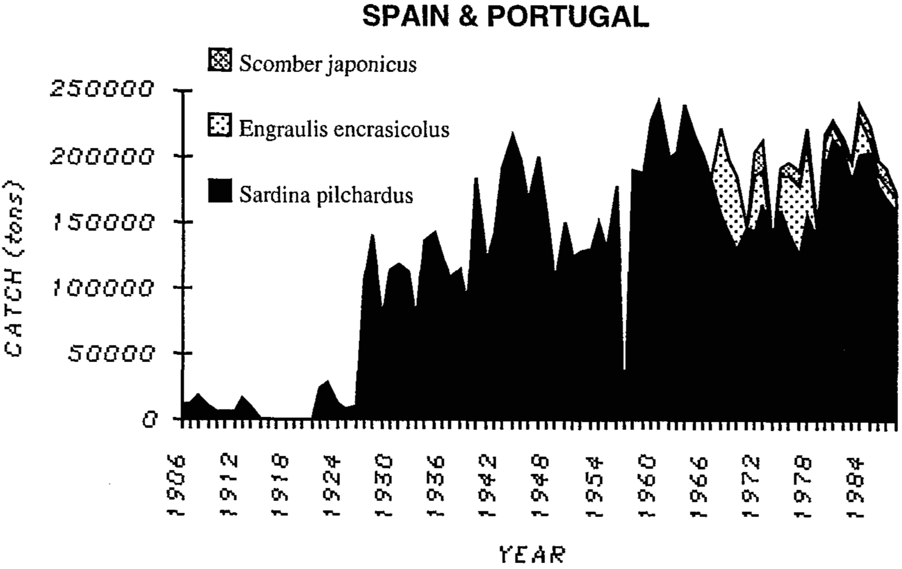

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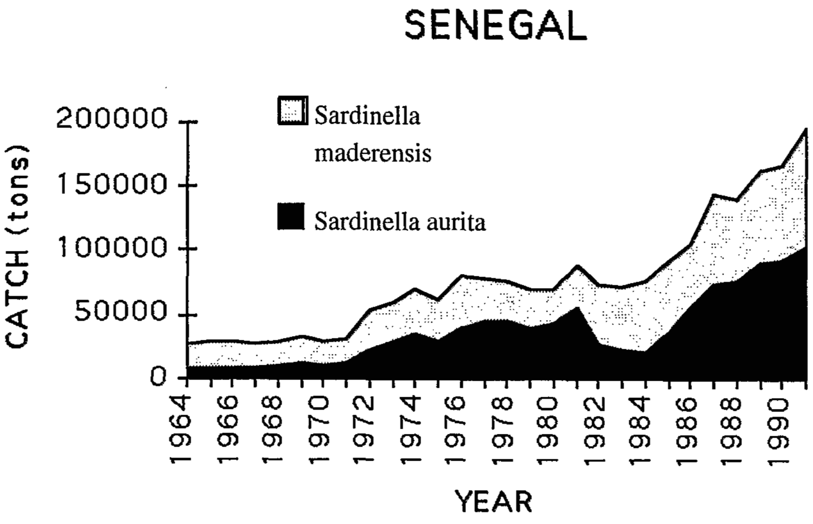

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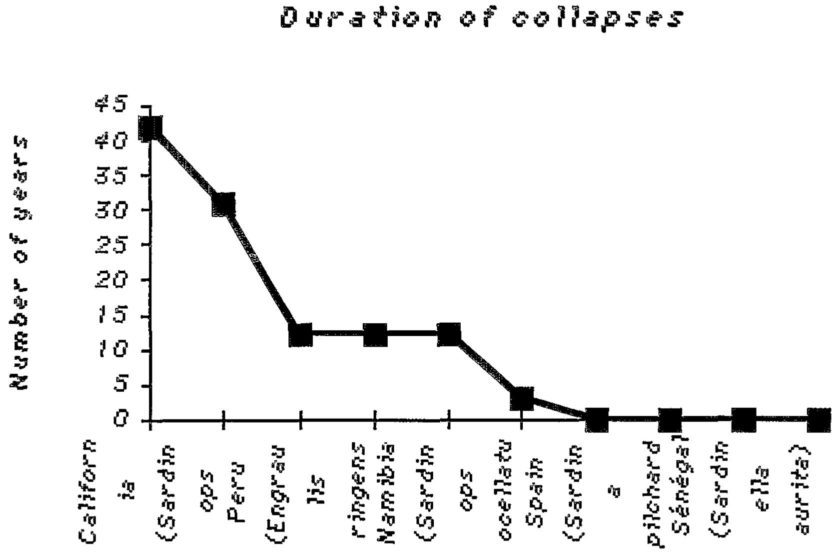

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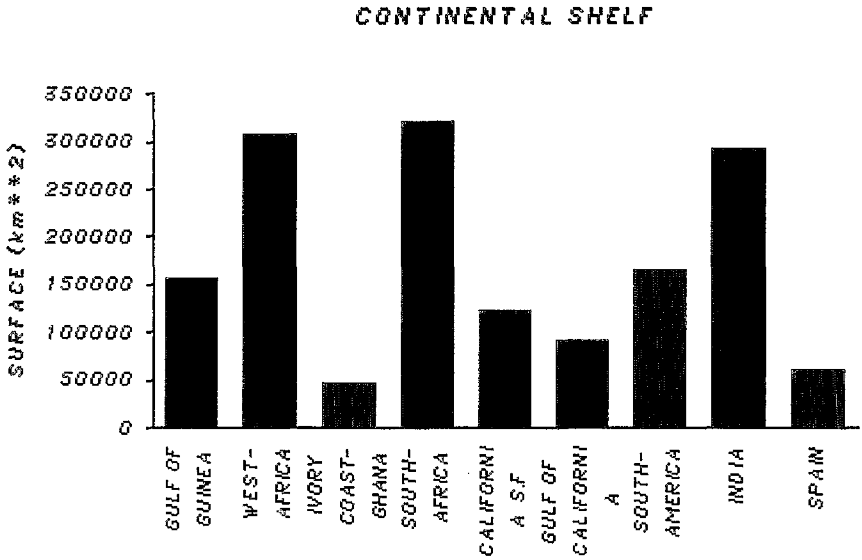

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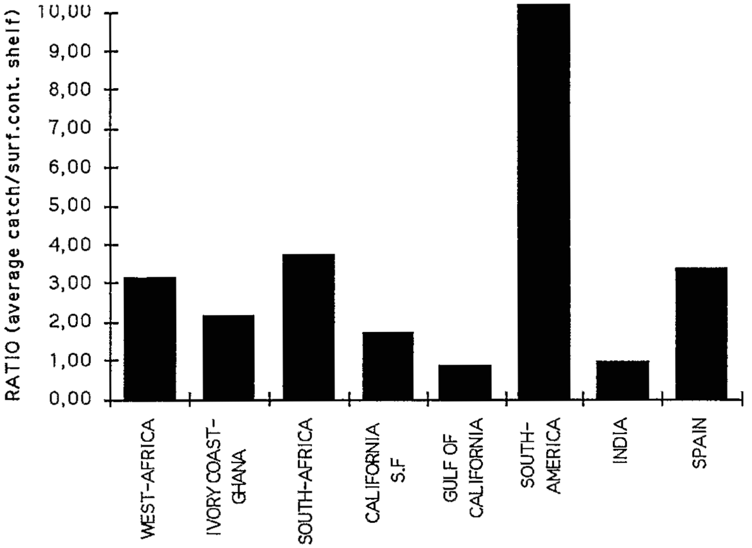

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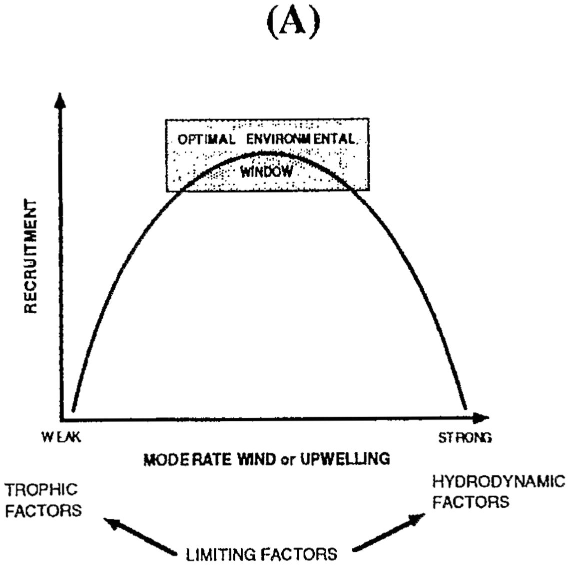

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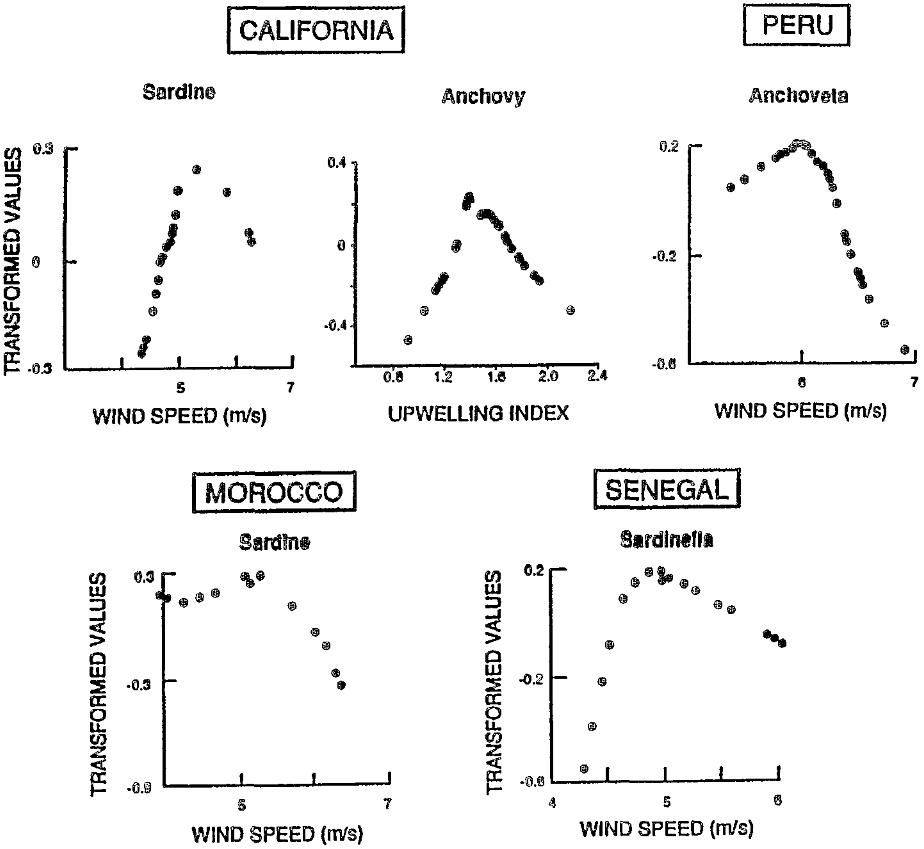

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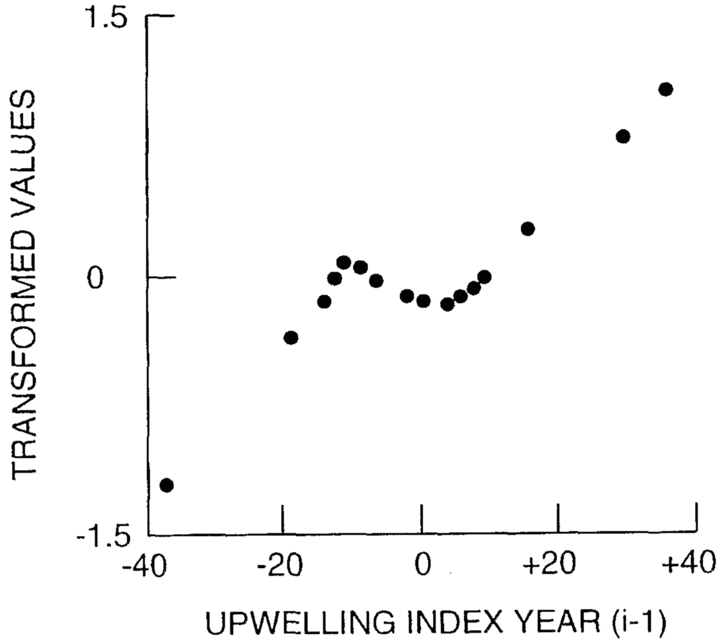

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