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IMPACT OF ENSO ON SURFACE TUNA HABITAT IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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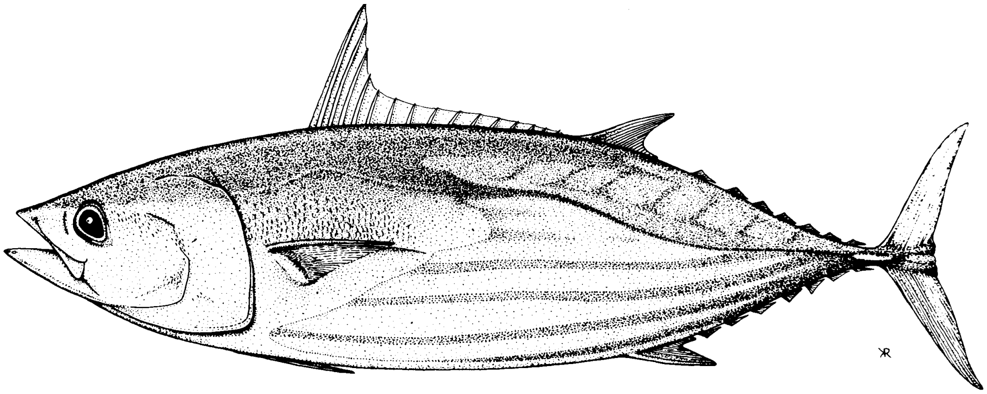

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Introduction

The central equatorial Pacific is characterized by the equatorial divergence, which generates an upwelling of relatively cold and nutrient-enriched waters, favorable to the development of a large zonal band with high levels of primary production, and frequently called the cold tongue. Contiguous to the cold tongue, the western Pacific warm pool is characterized by warmer water and low levels of primary production. However, when considering the higher trophic levels of the pelagic ecosystem, the differences between western and central Pacific are not as great as what is generally admitted, and may even be reversed for tropical tunas. Indeed, despite its low primary productivity rates, it is the warm pool that supplies the larger proportion of tuna catch (> 1 million t year^{-1}) in the Pacific Ocean (Fig. 1) and contributes approximately 40% of the world's annual tuna catch. This global catch is dominated by two tropical species, skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*), which inhabit the surface layer and feed mainly on epipelagic prey. This antagonistic east-west distribution of primary production and tuna abundance appears paradoxical at first sight. Recent findings on the oceanography of the equatorial Pacific, particularly on the ENSO cycle that characterizes its variability, and the results of a simulation model of tuna pelagic environment allow us to propose an explanation for this apparent paradox.

Observation

It is well established now that the zonal displacement of the warm waters of the western equatorial Pacific occurring during the development of an El Niño or La Niña event has a major impact on the distribution of the surface tuna stocks (Lehodey et al., 1997). The distribution of the abundance index (Catch Per Unit Effort) shifts longitudinally in concert with ENSO events distributed eastwards during El Niño phases, and westwards during La Niña phases. These zonal displacements are in correlation with the displacement of the eastern edge of the warm pool (over 50^{o} of longitude), identified by a salinity front or more approximately by the 29 or 28.5^{o}C isotherms. They are also correlated with the Southern Oscillation Index (SOI) (Fig. 2). With the improvement in the prediction of ENSO, such a correlation has important consequences for tuna fisheries management. In particular the activity in the different EEZs of the Pacific Island Nations will greatly vary according the situation in the Pacific. A stronger fishing activity will affect PNG during La Niña while during El Niño the Kiribati will have much more fishing vessels in their EEZ.

Although the spatial displacement of tuna abundance is clear, it could be attributed to a change in the capturability, e.g., because the thermocline deepens during an El Niño in the western Pacific. Therefore it is important to consider the real physical movements of tunas. Thanks to the large tagging experiments carried out by the Oceanic Fisheries Programme, it was possible to select tagged fish with a period of liberty at sea corresponding to the development of a La Niña and a El Niño (Fig. 3). These tagging data demonstrate that skipjack are largely able to cover the distances related to the displacements of the eastern edge of the warm pool. Moreover, the movements of this tagged fish are in a really good agreement with the direction of the displacement observed in the abundance as reflected by the catch rates.

Hypothesis

Considering the large biomass of tuna retained in the warm pool, a strong correlation between warm (>28^{o}C) water and high tuna abundance could be expected. However, at the scale of the Pacific basin, it is not so clear. In fact, there are large fisheries of same tuna species occurring in water between 20 and 25 ^{o}C (e.g., in the eastern Pacific or off Japan and New Zealand during summer season). Therefore, although probably important, the temperature does not seem sufficient to explain the distribution and movement of tunas. Beside, the demonstration could be the same with the salinity (Fig 2). In fact, although very large stocks of tuna are associated to the warm and relatively fresh waters of the warm pool, these two physical parameters are not sufficient to explain high abundance of surface tuna at the basin scale. A plausible hypothesis is that the tuna spatial distribution is linked to the search of food within suitable environmental conditions. Unfortunately, there are few observations on the distribution of the tuna forage, and to investigate this hypothesis it is necessary to use a modelling approach, based on our knowledge of the pelagic foodweb.

Modelling

The model developed to simulate the distribution of tuna forage at a large horizontal scale is based on simple and realistic assumptions and emphasizes the role of the oceanic circulation in the spatial redistribution of the forage. It makes the assumption that during the period of trophic conversion, redistribution of primary/secondary production occurs under the influence of surface currents. The inputs in the model are consequently the oceanic currents and the (new) primary production level (see Lehodey et al., 1998 for details). These data sets are provided by the LODYC (Laboratoire d’Océanographie et de Dynamique du Climat, France) where an oceanic general circulation model (called OPA) was coupled to a bio-geochemical model (Stoens et al., 1997, 1999) to predict the new primary production (P). The tuna forage model is a simple integrative dynamical spatial model based on the trophic continuum in the pelagic food web with a size-related time scale. The transport is described by a diffusion-advection equation using for the advective terms the zonal and meridional components of the current in the euphotic layer. The variation of the forage (F) in time is the result of three processes: the transport, the loss and the source (the new primary production). In fact, the model presents a large similitude with a classical fish population dynamic approach, when considering the case of a fish population with a continuous recruitment and a constant mortality. However, instead to have different age classes for the same species, there are different age classes in which the different species constituting the planktonic community disappeared selectively in the order of their trophic level, which is related to their size and to the time. Therefore, this simple model has only four parameters. The diffusion coefficient (constant and based on results of buoy drifts), a loss coefficient (m_r) which will affect the quantitative ecological transfer, and T_r (time at recruitment) and λ (mortality of the forage) that are fixed according to the biological characteristics of the forage population. The model is very flexible and can be used to describe short-lived zooplankton as well as the micronekton supposed to be the tuna forage.

Tuna habitat

By combining the spatial distribution of forage with a temperature function defined for the species according to our knowledge of their physiology and behavior, we obtain a habitat index used to reproduce the zones most favorable for the species. The figure 4 shows the evolution of habitat index distribution for skipjack tuna during the development of an El Niño cycle with the superimposition of high tuna catch rates of the U.S. purse seine fleet. The index shows that in the mid-year of 1994, when the El Niño reached its maximum development, a very attractive area for surface tunas appeared in the central Pacific, with effectively high catch rates of the purse seine fleet. As the oceanographic conditions return to a normal situation, the attractiveness decreased in the central Pacific and increased in the western Pacific. In the beginning of 1995, when normal conditions are prevailing, the US purse seine fleet has moved westward where the attractiveness was increasing.

Synthesis

In summary, it is possible to describe a conceptual model of the impact of ENSO on tuna habitat in the WCPO. During a mean situation, the well-developed equatorial divergence produces a cold tongue with a high level of primary production extending to the date line. The equatorial divergence within a mean westward zonal flux creates a spatial shift in the planktonic communities both on the meridional and zonal axes. In the western equatorial Pacific, primary productivity is generally low except in the vicinity of islands. With the development of an El Niño, the system shifts eastward. One part of the secondary production, which was developing from the cold tongue in the previous months, penetrates the warm pool. This zone is highly favorable to the tuna predation by surface tuna. As the atmospheric convective zone is displaced towards the central equatorial Pacific, stronger wind stress than usual leads to an increase of primary production in the western Pacific. As soon as the eastward displacement of the system reverses, the eastern edge of the warm pool becomes less attractive. On the other hand, the PNG-Indonesian regions has developed an increased zooplankton and micronekton biomass, increasing the attractiveness and possibly explaining the rapid westward movement of tuna observed during this phase.

Acknowledgments

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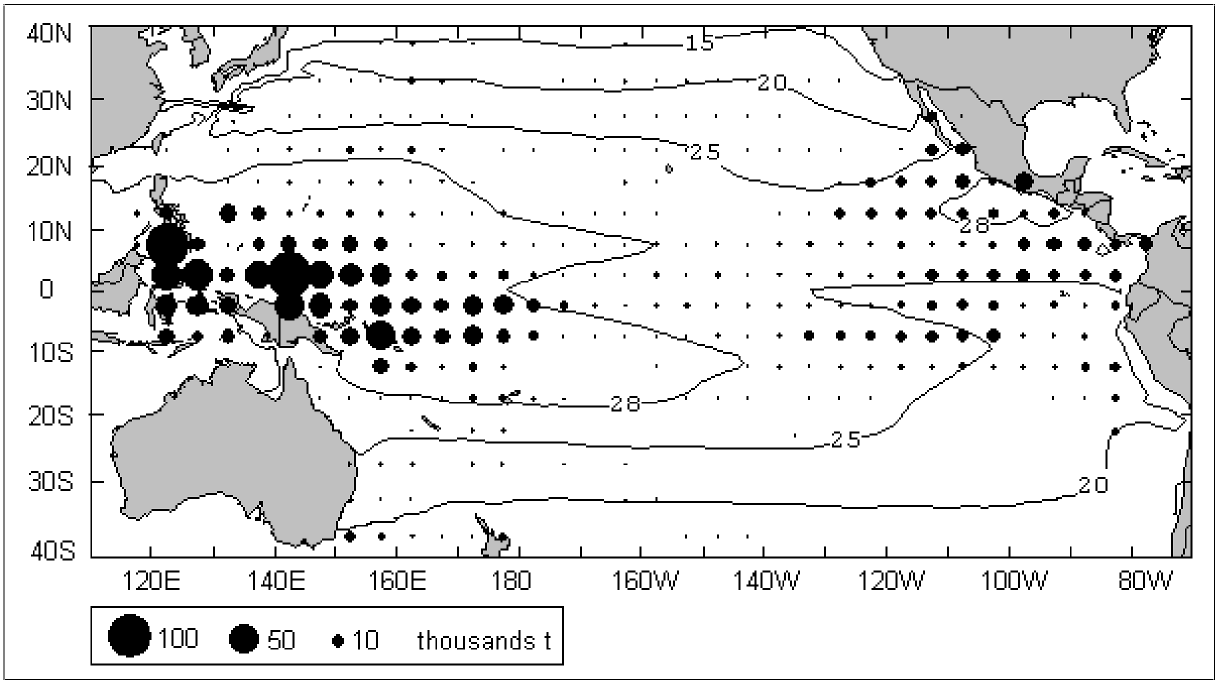

Figure 1. Total catch of tuna (yellowfin, skipjack, bigeye, albacore) in the Pacific Ocean and mean SST for 1996 (all gears and fleets, aggregated data by square of 5°)

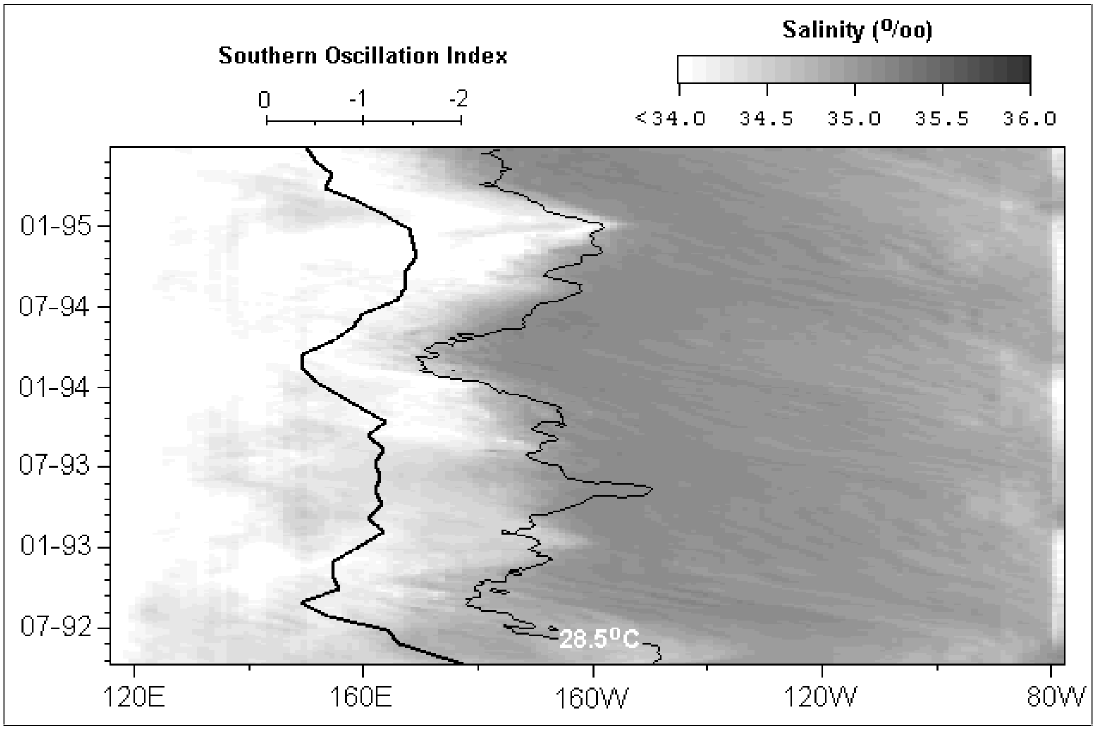

Figure 2. Longitude-time plot of sea surface salinity in the equatorial band 5°N-5°S showing the well-marked salinity front on the eastern edge of the convergence zone (redrawn from Lehodey et al. 1998). The 28.5°C isotherm can be used as a proxi for the localization of the front. Zonal displacement of the front are in phase with ENSO (defined with the Southern Oscillation Index).

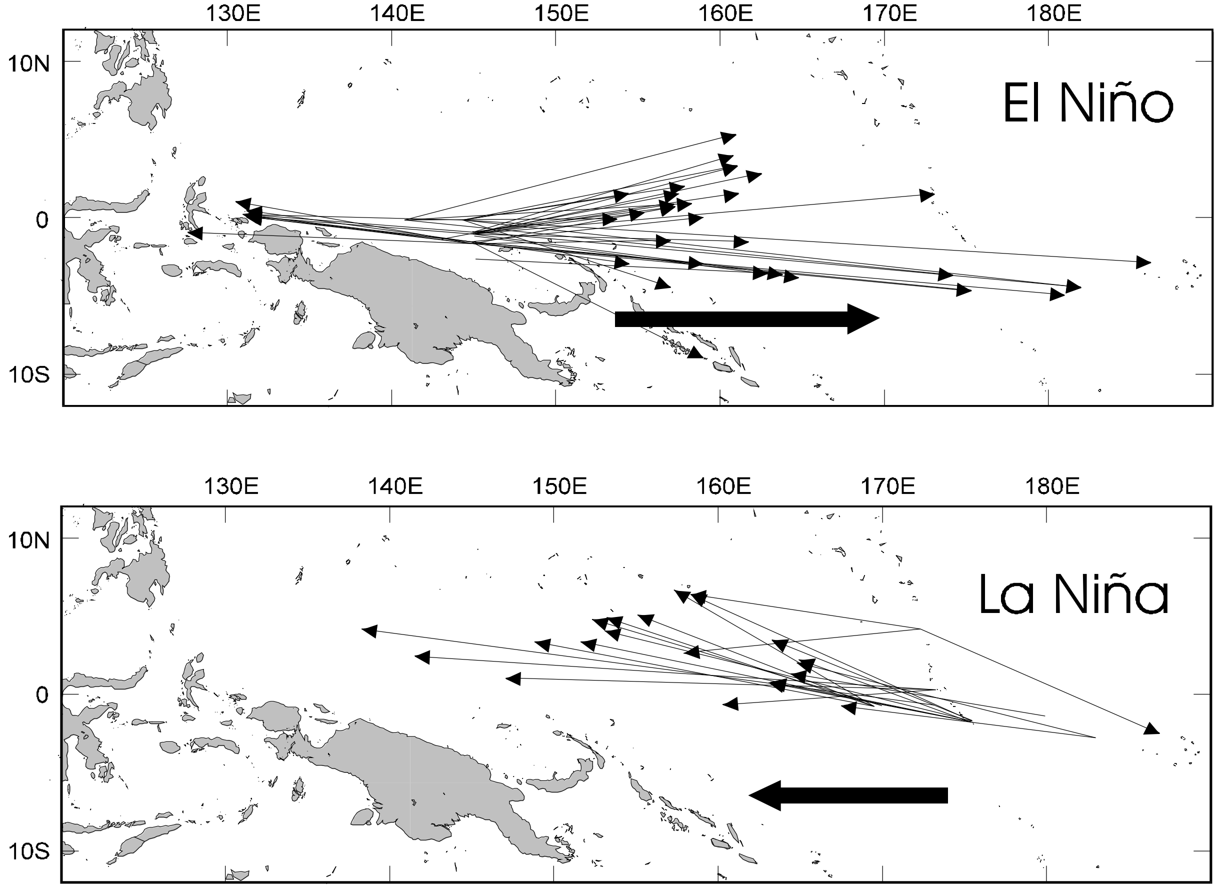

Figure 3. Displacement of tagged skipjack tuna during an El Niño (May 1991- Feb. 1992) and La Niña (Mar. 1992 – Oct. 1992) phase. (Redrawn from Lehodey et al., 1997)

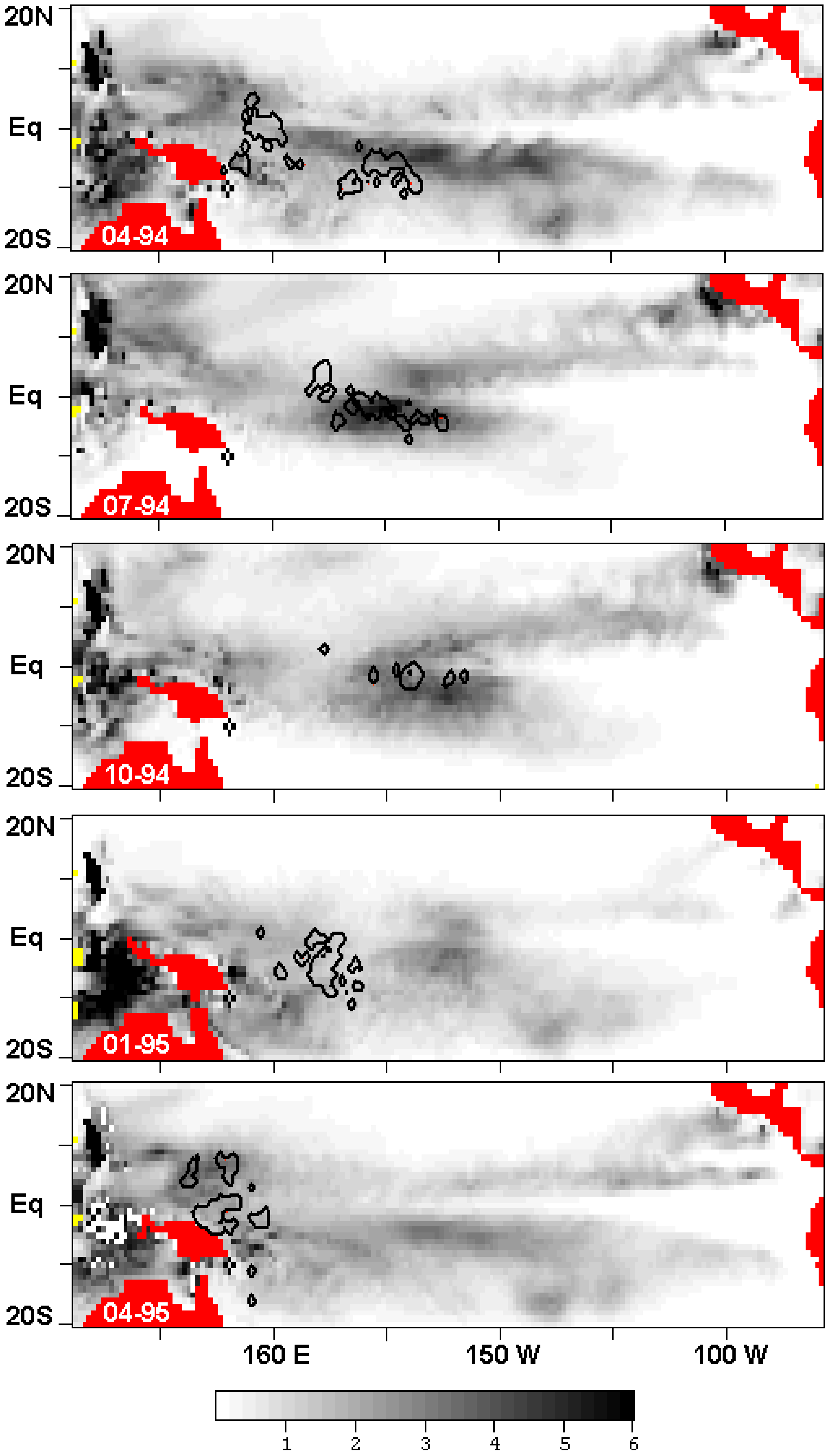

Figure 4. Skipjack habitat index and contour of U.S. purse seine catch rates > 5t /day in the western and central Pacific Ocean