Variation in yellowfin tuna (*Thunnus albacares*) catches related to El Niño-Southern Oscillation events at the entrance to the Gulf of California

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Abstract—Fishery catch data on yellowfin tuna (*Thunnus albacares*) were examined to study the effects of El Niño events between 1990 and 1999 for an area in the northeastern tropical Pacific (18–24°N, 112–104°W). The data were extracted from a database of logbook records from the Mexican tuna purse-seine fleet. Latitudinal distribution of the catches increased from south to north for the 10-year period. Highest catches and effort were concentrated between 22°N and 23°N. This area accumulated 48% of the total catch over the 10-year period. It was strongly correlated with El Niño-Southern Oscillation (ENSO) events. At least two periods of exceptionally high catches occurred following El Niño events in 1991 and 1997. Peaks of catches were triggered by the arrival of positive anomalies of sea surface temperature (SST) to the area. A delay of two to four months was observed between the occurrence of maximum SST anomalies at the equator and peaks of catch. Prior to these two events, negative SST anomalies were the dominant feature in the study area and catch was extremely low. This trend of negative SST anomalies with low catches followed by positive SST anomalies and high catches may be attributed to northward yellowfin tuna migration patterns driven by El Niño forcing, a result that contrasts with the known behavior of decreasing relative abundance of these tuna after El Niño events in the eastern Pacific. However, this decrease in relative abundance may be the result of a local or subregional effect.

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The entrance to the Gulf of California (from 18°N to 24°N and 104°W to 112°W) is located in the convergence zone of the North Pacific Gyre, where the California Current separates from the coast to feed the North Equatorial Current. It has a complex hydrographic structure due to the confluence of different water masses (Roden and Groves, 1959; Roden, 1972; Álvarez-Borrego and Schwartzlose, 1979; Bray and Robles, 1991; Torres-Orozco, 1993). This region is highly responsive to the El Niño phenomenon. Its main response is characterized by positive sea level anomalies, warming of the upper layer, and a general alteration of water current patterns (Baumgartner and Christensen, 1985; Robles and Marinone, 1987; Torres-Orozco, 1993; Lavín et al., 1997; Ortega-García et al., 1999; Trasviña et al., 1999; Castro et al., 2000; Bernal et al., 2001).

High abundance of yellowfin tuna (*Thunnus albacares*; YFT) is reported in the study area (Allen and Punsly, 1984; Castro-Ortiz and Quiñones-Velásquez, 1987; Muhlia-Melo, 1993; Ortega-Garcia, 1998). However, studies about the YFT interaction with the physical environment of the Mexican Pacific are lacking. Blackburn (1965, 1969) considers that the abundance of the YFT correlates with sea surface temperature (SST) in the range of 20°C to 30°C, but it can also be present in regions having temperatures between 18°C and 31°C. Blackburn (1969) considered 30°C as an optimal estimate of the maximum temperature of occurrence of YFT. Similarly, Ortega-García (1998) reported that YFT are distributed in regions where SST ranges from 17°C to 31°C and that they are frequently observed in waters close to 28°C. Other studies such as that of Laevastu and Rosa (1963) and Castro-Ortiz and Quiñones-Velasquez (1987) have indicated that YFT are found at concentrations favorable to commercial fisheries in regions where the SST ranges from 20°C to 28°C. In summary, YFT catches are historically reported to occur at SST values ranging from 12° to 30°C, and favorable catches are reported between 17° and 25°C (Lehodey[1]). More recently, Bautista-Cortes (1997) has studied the relationships between varying vertical temperature structure and YFT catches in the Mexican Pacific to 140° longitude W, finding that the depth of the 23°C isotherm is related to catch and that the shallower the isotherm, the larger the tuna catches.

Castro-Ortiz and Quiñones-Velasquez (1987) reported reduced catches of YFT during the 1982–83 El Niño events in the northeastern Pacific, in contrast to the following 1984–85 seasons. The 1982–83 El Niño event was reported to have caused the largest decrease in the availability-vulnerability index ($AVI=CPUE/(1-SSR)$; where SSR is the successful-set ratio and $CPUE$ is catch per unit of effort; IATTC[2]). This finding is consistent with the resource being less susceptible to fishing in the northeastern Pacific during an intense El Niño. Lehodey[1] analyzed data of purse-seine and longline CPUE of skipjack (*Katsuwonus pelamis)*, yellowfin (*Thunnus albcares*), bigeye (*Thunnus obesus*), and albacore (*Thunnus alalunga)* tunas during El Niño and La Niña events, from 1982 to 1998 for the whole tropical Pacific Ocean (20°S to 20°N). He concluded and supports the hypothesis that ENSO affects the recruitment of skipjack, yellowfin, and bigeye tunas positively in the western Pacific. A direct positive effect related to the vertical change in the thermal structure during El Niño increased purse-seine catches of yellowfin in the western Pacific. He suggested two theoretical cases be considered for yellowfin and bigeye in the eastern Pacific: either a positive La Niña effect on the recruitment and catchability, or conversely a positive El Niño effect on recruitment and catchability. His statistical analysis did not identify the direct effects of ENSO on catchability for yellowfin and bigeye tunas. He suggested the need for additional analyses in the eastern Pacific region and for comparisons with independent results from modeling and observations to confirm the preliminary results. Lu et al. (2001) analyzed catches of YFT and bigeye tuna caught by the longline fleet of the tropical Pacific Ocean. They concluded that high hook rates for both species were mostly associated with regions where SST increased during El Niño or La Niña years. During La Niña episodes, YFT populations appear to undergo a poleward displacement thus shifting both north and south of the equator. During El Niño events YFT populations in the equatorial Pacific are found where SST anomalies are higher, in the central and eastern equatorial Pacific.

For the region of interest, Ortega-García et al. (1999) studied the impact of the ENSO during the 1997–98 El Niño events in comparison to the 1996–97 non El Niño year within the eastern Pacific Mexican purse-seine tuna fishery. They reported that during the first months of the ENSO (July–December 1997) of the El Niño event, the extent of the YFT catches was higher in oceanic waters than the observed catches during a non El Niño year in these areas for the same period. A decline of effort was observed along the coast of Baja California and inside the Gulf of California. In contrast, during the second part of the ENSO El Niño 1997–98 (January–June 1998), an increase of effort was observed along the coasts of Baja California and inside the Gulf of California; however, a decrease of effort was observed in oceanic areas.

The relative abundance of YFT in the eastern Pacific is reported to diminish during El Niño events; however, as supported by the IATTC[2] report, the YFT vertical displacement during El Niño events generates a diminishing fishing effort for the purse-seine fleet in traditional catch areas. As a consequence, this has led to a good recruitment and greater yield-per-recruitment. Large recruitments after El Niño events are reported to occur in the eastern Pacific. Joseph and Miller[3] analyzed YFT catch data from the eastern Pacific for a 22-year period and found positive anomalies in tuna recruitment after El Niño events. Large recruitments were observed in years 1971, 1974, 1978 and 1985, all of which were preceded by the El Niño events of 1969, 1972, 1976, and 1983, respectively.

The objective of the present study was to examine the effect of the ENSO El Niño and La Niña events for a 10-year period (1990–99) on YFT catches in the entrance to the Gulf of California, an area of importance for the industry and for the ecology of the resource in the eastern Pacific.

Materials and methods

The classification of El Niño intensities was taken from the Climate Prediction Center (NOAA[4]). The process of classification takes into account re-analyzed SSTs produced at the National Centers for Environmental Prediction (NCEP), at the Climate Prediction Center, and at the United Kingdom Meteorological Office.

Environmental data in the form of monthly means of sea surface temperature anomalies (SSTAs) from 1990 to 1999 were extracted from the NCEP monthly SSTA data-

[1] Lehodey, P. 2000. Impacts of the El Niño Southern Oscillation on tuna populations and fisheries in the tropical Pacific Ocean. Working Paper. RG-1, 32 p. Oceanic Fisheries Programme, Noumea, New Caledonia, Secretariat of the Pacific Community. http://www.spc.org.nc/OceanFish/Html/SCTB/SCTB13/rg1.pdf [accessed on 20 February 2002].

[2] IATTC (Inter American Tropical Tuna Commission). 1989. Annual Report of the Inter-American Tropical Tuna Commission, 1988. Annu. Rep. IATTC, 288 p. http://www.iattc.org/PublicationsSPN.htm [accessed on 11 March 2002].

[3] Joseph, J., and F. R. Miller. 1988. El Niño and the surface fishery for tunas in the eastern Pacific. *In* Proceedings of tuna fish. res. conf., p. 199–207. Japan Fish. Agency-Far Seas Fish. Res. Lab. Muguro Gyogyo Kyogikai Gjiroku, Suisancho-Enyo Suisan Kenkyusho.

[4] NOAA (National Oceanic and Atmospheric Administration). 2001. Cold and warm episodes by season. Website: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.html [accessed on 10 January 2002].

base (IRI[5]). The SST fields were blended from ship, buoy, and bias-corrected satellite data. A description of this procedure can be found in Reynolds and Smith (1994). SSTA data for El Niño region 3 (NIÑO3, from 150°W to 90°W and from 5°N to 5°S) were obtained from Climate Prediction Center databases (CPC[6]).

Yellowfin tuna catch data were obtained from the database of the ATUN (tuna) Project of CICIMAR (the Interdisciplinary Research Center of Marine Science of the National Polytechnic Institute in La Paz, Mexico). This database has information on daily fishing activities for about 80% of the Mexican purse-seine fleet operating in the eastern Pacific. The data used in the present study include carrying capacity, catch-by-species, location, and school type (YFT associated with dolphins; YFT associated with floating objects; and free-swimming YFT), from 1990 to 1999, comprising 11,690 records. Total distribution of the sets made by the Mexican purse-seine fleet from 1990 to 1999 at the entrance of the Gulf of California is shown in Figure 1.

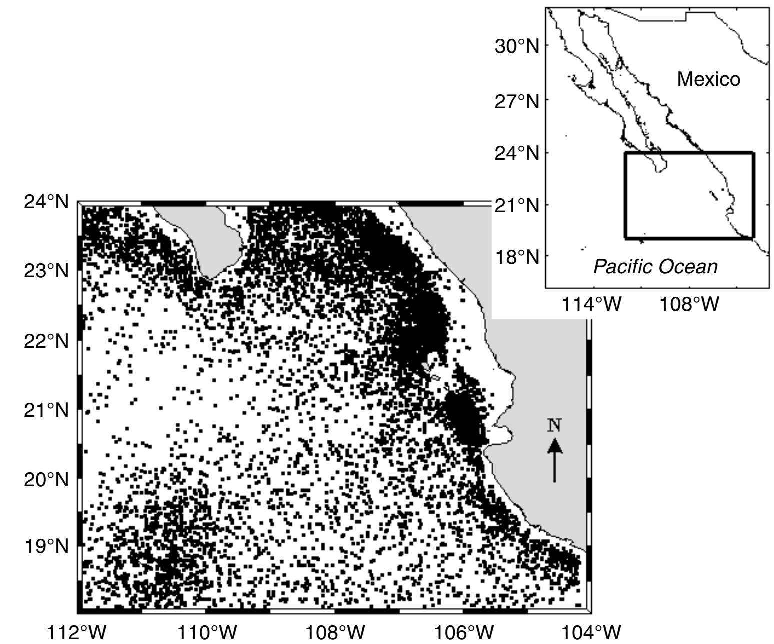

Figure 1

Total distribution of the sets made by the Mexican purse-seine fleet during 1990 to 1999 at the entrance to the Gulf of California. Catch data for yellowfin tuna (*Thunnus albacares*) were obtained from the CICIMAR (the Interdisciplinary Research Center of Marine Science of the National Polytechnic Institute in La Paz, Mexico).

Interannual variation

In order to study annual variation, total catches of YFT of the purse-seine fleet within the study area were accumulated by year. A cross-correlation analysis was applied to obtain information on lags between SST anomalies and YFT catches.

Latitudinal stratification

In order to analyze the latitudinal catch variation of YFT within the study area, catch data for the period 1990–99 were accumulated in six latitudinal bands of one degree from 18°N to 24°N at the entrance of the Gulf of California. Longitudinal limits extended from the coastal line of the Mexican continent (from 104°W to 112°W).

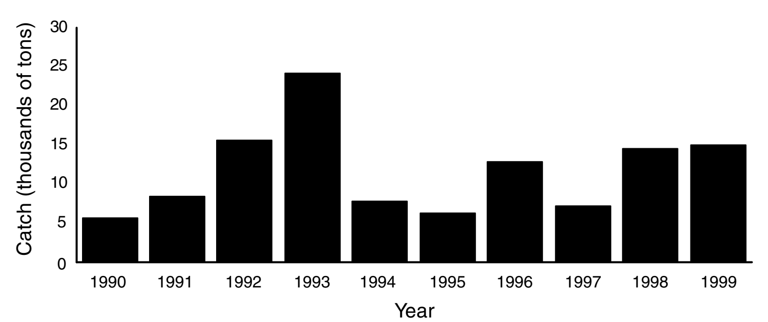

Figure 2

Total catch for yellowfin tuna (*Thunnus albacares*) by year during 1990–99 in the study area.

Results

Interannual variation in YFT catch

The catch of YFT in the study area showed high interannual variation (Fig. 2). This high variation showed substantial increments, 85% from 1991 to 1992, 54% from 1992 to 1993, 102% from 1995 to 1996, and 102% from 1997 to 1998. In particular, the sum of the two El Niño years in the record (1991–93, 1997–98) represents 59.5% of the total catches over the 10-year period.

Latitudinal variation in YFT catches

Figure 3 shows the variation of catch and effort (in sets) from 1990 to 1999. Vertical bars include catches from different one-degree latitudinal range areas between 18°N and 24°N and meridional ranges between 104°W to 112°W (Fig. 1). With the exception of the southern 18–20°N area,

[5] IRI (International Research Institute for climate prediction). 2002. Sea surface temperature anomaly data. Website: http://ingrid.ldgo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.GLOBAL/.Reyn_SmithOIv1/.monthly/.ssta/ [accessed on 9 February 2002].

[6] CPC (Climate Prediction Center). 2002. Monthly atmospheric and SST indices. Website: http://www.cpc.ncep.noaa.gov/data/indices/index.html [accessed on 9 February 2002].

there is a general linear increase of catch with latitude. Fishing effort was concentrated in the 22–23°N and 23–24°N areas. Both account for 48% of the total capture for the 10-year period in this region. From 18° to 21°N, catch values averaged 12.9% of the total catch.

Yellowfin tuna catches affected by ENSO events

Sea surface temperature anomalies (SSTA) were used to investigate the effect of interannual warming or cooling events on the variability of YFT catch. Anomalies for

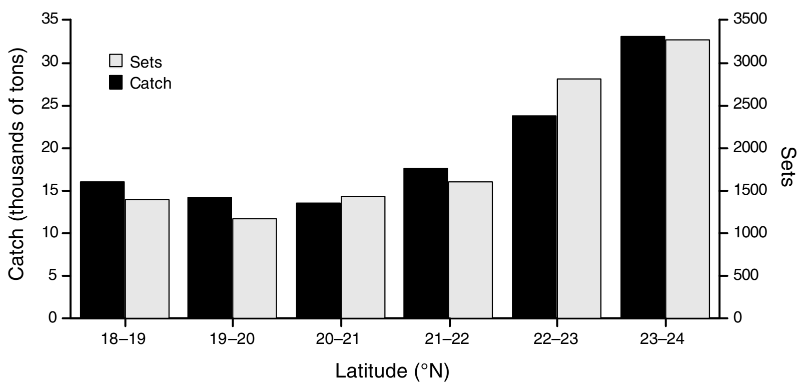

Figure 3

Latitudinal distribution of catches of yellowfin tuna (*Thunnus albacares*) for the period 1990–99.

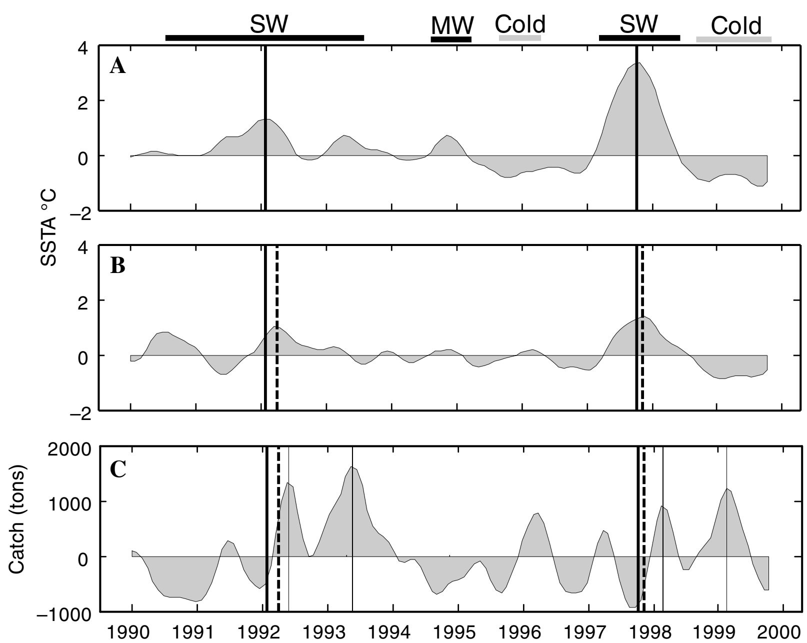

Figure 4

Sea surface temperature anomalies (SSTAs) in the El Niño region 3 (**A**), SSTAs in the study area (**B**) and catches of yellowfin tuna (*Thunnus albacares*) (**C**). Bars at the top show the equatorial central Pacific episodes as compiled by the Climate Prediction Center (see "Methods" section): Strong warm (SW) peaks of catch are indicated by thin vertical lines. Thick vertical lines indicate maximum SST anomalies in NIÑO3 (A). Dashed vertical lines indicate peaks of SSTA in the area of study (B). Moderate warm (MW) and cold episode. The maximum intensity of the warm episodes is marked with dashed lines (B and C).

the entrance to the Gulf of California were calculated between 22°N and 23°N and 103°W to 112°W. These anomalies were extracted from the Reynolds and Smith (1994) monthly 1-degree SSTA climatology. This variable was then compared to the catch of YFT. We did not examine SSTAs south of 21°N because they fall within the Mexican Warm Pool (Trasviña et al., 1999), where persistently high SSTs (above 27°C all year in the warm pool region) mask the propagation of warm and cold signals from the Equator. The 10-year time series (1990 to 1999) was "detrended" and filtered to eliminate periods shorter than three months, as described in Godin (1972).

SSTAs in the NIÑO3 (Fig. 4A) showed cold and warm conditions associated with five identifiable events. These events were the following: 1) warm El Niño events in 1991–92 (strong warm, SW), 2) in 1994–95 (moderate warm, MW), and 3) in 1997–98 (strong warm, SW); 4) moderately cold La Niña events that took place in 1995–96 and 5) in 1998–99. Strong warm events are marked with a black line located at each respective maximum SSTA (Fig. 4). The 1997–98 was the strongest warm episode in the 1990–99 decade.

The 1991–92 and 1997–98 SSTAs in El Niño region 3 were higher, by more than 1°C, than the SSTAs in the study area (Fig. 4, A and B). Within the 10-year period, near-normal conditions occurred from 1993 to 1996. The coldest and most persistent event of this decade took place in the study area from July 1998 to December 1999, i.e., during a moderate La Niña event.

Significant interannual variability of YFT catches was observed during the 10-year period in the study area (Fig. 4C). This graph shows the time series of monthly values of YFT catch anomalies related to the average for the 10-year period. Five exceptionally high catch events in years 1992, 1993, 1996, 1998, and 1999 were observed. These years account for 70% of the total capture during the 10-year period.

Several qualitative and quantitative features were apparent from these results:

1 Catch peaks in 1992 and 1998 occurred 3 (r=0.73) and 4 (r=0.64) months, respectively, after the onset of an El Niño event at the equator (time span between thin and thick lines) (Fig. 4, A and C).
2 High catches of YFT at the entrance of the Gulf of California in 1992 and 1998 occurred 2 (r=0.71) and 3 (r=0.73) months, respectively, after the SST anomaly signal reached the study area (time span between dashed and thin lines) (Fig. 4, B and C).
3 Higher catches of YFT occurred during the spring following an El Niño winter. These were observed in the spring of 1992 and 1998 (thin lines; Fig. 4C).
4 Peaks of YFT catch were also observed in 1993 and 1999. These occurred one year after the El Niño event. The 1993 peak took place in nearly normal SST conditions, whereas the 1999 peak occurred during negative SST anomalies (La Niña event, Fig. 4, B and C). These peaks of YFT catch were higher than the ones recorded in the previous year during the El Niño event 1991–92 and during 1997–98.

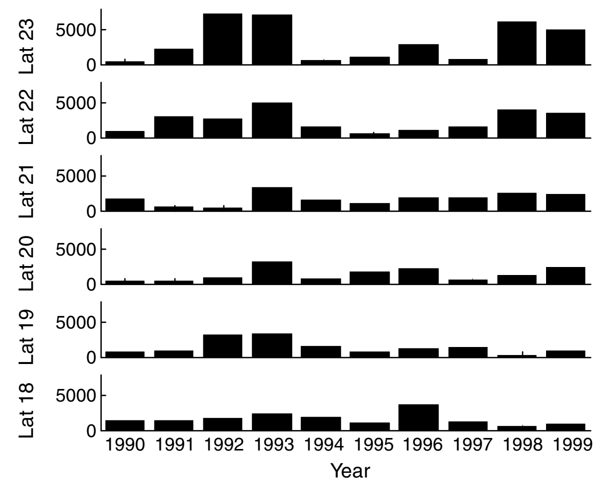

Figure 5

Annual catches (in tons) of yellowfin tuna (*Thunnus albacares*) in latitudinal bands within the area of study for the period 1990–99.

5 The 1996 peak seemed not to be related to the variability of SST anomalies alone.
6 There was a delay from one to two months between the mature phase of the El Niño event at the equator and the presence of high SSTAs in the study area (time span between thick and dashed lines in Fig. 4, A and B).

Annual YFT catches of stratified latitudinal bands within the study area are shown in Figure 5. A progressive increase in YFT catches from southern to northern latitudes was observed in years 1993 and 1999. This progressive increase may be indicative of a northward movement of the resource. This phenomenon has been observed in the western tropical Pacific Ocean during La Niña events where YFT have dominated the longline catch (Lu et al., 2001).

Discussion

Catch affected by the onset El Niño

Cross-correlation between the onset of El Niño at the equator in 1991–92 and 1997–98 with catch peaks of YFT in the study area showed a delay of three and four months respectively. Catch peaks of YFT at the entrance of the Gulf of California in 1992 and 1998 occurred two to three months after the SSTA signal reached the study area. These results are similar to those found by Lehodey[1] in the western and central regions of the Pacific Ocean, where rising (deepening) of the mixed-layer depth related to El Niño (La Niña) was associated with an increase in the pole-and-line and purse-seine CPUE of YFT and where there was a concomitant delay of two to three months in this increase.

Catch of YFT in relation to recruitment

Recruitment explains most of the YFT catch fluctuations in relation to El Niño events at the entrance of the Gulf of California. A recurrent pattern in the time-series of the catch revealed a peak of catch fourteen (1993) to twelve (1999) months following an El Niño event. A similar result has been observed in a cross-correlation between the Southern Oscillation index (SOI) and the long-line series of catch data for yellowfin tuna; a positive correlation was found in the eastern Pacific region after a lag of fourteen months (Lehodey[1]). This finding supports the hypothesis of a recruitment base (age-effect) for yellowfin because at 14 months YFT reach 75 cm, corresponding to the first age class recruited to the long-line fishery. These results are also consistent with those from previous analyses of time-series of catches of YFT in the eastern Pacific, namely by Joseph and Miller[3] and the IATTC[2]. Therefore, recruitment can be the major explanation of the YFT catch fluctuations in relation to El Niño events at the entrance of the Gulf of California.

Catch distribution of YFT related to ENSO episodes

For the long-line fishery in the tropical Pacific Ocean, areas with significant higher hook rates of YFT during El Niño years are located east of 150°W within tropical waters of the central eastern Pacific (Lu et al., 2001). Conversely, higher hook rates occur during La Niña episodes in areas where SSTs rise during El Niño events. These two findings may provide two possible reasons for the change in hook rates: the expansion of optimal habitat and the change in vulnerability of the resource to the fishing gear during the ENSO episodes.

Conclusions

At the entrance of the Gulf of California, an El Niño event is associated with an increase in the purse-seine catch of YFT after two to three months, when SSTAs reach the study area. Similarly, this increase is delayed three to four months after the onset of El Niño at the equator.

A positive correlation of El Niño on YFT catch at the entrance of the Gulf of California after a twelve to fourteen month delay supports the hypothesis that the ENSO affects recruitment of YFT. This correlation seems to be independent of the thermal structure during the recruitment phase. In 1993, normal conditions in SST were present, whileas in 1999 La Niña was observed.

A northward displacement of YFT seems to occur at the entrance of the Gulf of California twelve to fourteen months after El Niño events. Lower catches in southern latitudes were recorded, whereas higher catches were recorded in northern latitudes. Similar results have been observed in the central Western Pacific for the long-line fishery (Lu et al., 2001).

Forecasting catch within the study area may give us the ability to reliably develop predictions of catch following El Niño or La Niña events.

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