INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

RELATION BETWEEN CAPTURE OF *Scomberomorus sierra* (PERCOIDEI:SCOMBRIDAE) WITH SEA SURFACE TEMPERATURE AND CHLOROPHYLL *a* OFF THE COAST OF THE CENTRAL MEXICAN PACIFIC (2003-2013)

Marine biology

Castro-Garibay H.	Posgrado en Ciencias del Mar y Limnología, UNAM, CDMX, México
Gallardo-Cabello M.	Instituto de Ciencias del Mar y Limnología, UNAM, CDMX, México
Espino-Barr, E.*	INAPESCA, Playa Ventanas s/n, Colima, México. *Corresponding Author
Salmerón García O.	Instituto de Geografía, UNAM, CDMX, México
Aguirre-Gómez R.	Instituto de Geografía, UNAM, CDMX, México

ABSTRACT

Chlorophyll *a* concentrations (CHLOa) and nocturnal sea surface temperature (NSST) off the coast of Jalisco and Colima, México (106°-101°W, 18°-23°N) from 2003 to 2013 were related to the capture of sierra *Scomberomorus sierra* (data obtained from Arrival Reports). Data of CHLOa showed an inverse proportional relation with NSST. From February to April NSST had a lower average than 25°C and in this period CHLOa had the highest value. From July to October CHLOa reached its minimum value and NSST an average of 29°C. CHLOa concentrations reached its highest value at a distance of 0 to 6 nautical miles (nm) from the coast; from 18 to 24 nm values descended. During rainy season CHLOa maintained values higher than 2 mg·m^{-3} in areas near the coast, due to river flow. With the NSST compound, the presence of a coastal current was detected from 0 to 6 nm from northwest to southeast direction, transporting water of lower temperature; signs of this current vanish in summer when the area reaches an isotherm. It was observed that most years show that the Oceanic Niño Index (ONI) and NSST have a significant correlation, being stronger in those years with a moderate phenomenon (Niño or Niña). Jalisco has higher catches of *S. sierra* than Colima, and variations from 18.5 t in March to 5.9 t in August. Most capture of *S. sierra* in Jalisco and Colima are from January to May and secondly in November and December. Significant correlations (p <0.05) were found between CHLOa and *S. sierra* catch, with changes from one year to the next. Significant inverse correlations (p<0.03) were found between NSST and *S. sierra* catch, higher than 70%, except 2003 and 2005. During 2003 three periods of distribution and reproduction of *S. sierra* were found: 1) January to May, high concentrations of CHLOa and a low NSST, coinciding with high values of the gonadosomatic (GSI), hepatosomatic (HIS) and gastric repletion (GRI) indexes. Also there are high registers of *S. sierra* capture. 2) From June to August high values of GSI and GRI were found, although there were low concentrations of CHLOa and a raise in the NSST, possibly the species secludes itself to zones with high concentrations of CHLOa thanks to the transportation of organic matter, therefore a drastic decrease of captures is observed. 3) From October to December the rainy season comes to its end, first in Jalisco and later in Colima, and from November on CHLOa starts to increase and NSST to decline; with this, a rise in captures is observed and also increments in the GSI, HIS and GRI, although values do not reach the first of the two periods.

KEYWORDS

Introduction:

A primary task to analyze fisheries is the fish population survey of a certain region during several years, because they are at expense of environmental fluctuations, interactions with other species and fishing pressure.

There are few studies characterizing the coast of Jalisco and Colima; the one of Gallegos *et al.* (2006) defines areas 500 km off the coast. Our study is divided in two parts: the first describes nocturnal sea surface temperature (NSST) and chlorophyll *a* (CHLOa) in the coast of Jalisco and Colima in the Central Mexican Pacific, using satellite compounds of 11 years (2003-2013); the second analyzes the relationships of these parameters with the artisanal fishing of *Scomberomorus sierra* Jordan y Starks, 1985.

Satellite compounds of NSST and CHLOa. This study analyzes monthly satellite compounds of CHLOa and NSST, processed from satellite images of moderate resolution (MODIS) by the Oceanic Monitoring System (SATMO) (CONABIO, 2011).

Study area. The coast of Jalisco and Colima is located in the central region of the Mexican Republic on the Pacific Ocean between the meridians 101 and 106 west longitude and the parallels 18 and 23 north. The length of their coasts is 351 km for Jalisco and 142 km Colima, which make up to 4.43% of Mexican coasts; the Pacific has 7828 km of which together Jalisco and Colima are 6.3% (INEGI, 2010). These states have rocky coasts and sandy beaches, and the continental shelf is very narrow (Ruiz-Durá, 1985). Jalisco has an average rainfall of 1 000 mm annually (INEGI, 2010), and Colima of 1 106 mm per year (2004-2013). Both states have a very marked rainy season from June to October, when 90% of the rain is concentrated.

This zone has the influence of currents that move in different directions depending on the season of the year. The main currents are: California Current (CC), Equatorial Counter Current (ECC), Costa Rica's Current (CRC) and North-Equatorial Current (NEC). An event with great influence in the region is the phenomenon of El Niño Southern Oscillation (ENSO), which is a climatic pattern that implies changes of the water temperatures in the central and oriental tropical Pacific. This phenomenon is not periodic, but recurrent and its intensity varies from one event to the next (NOAA, 2014).

Fig. 1. Photograph of *Scomberomorus sierra*, showing the maximum length worldwide and its relation to a man 1.7 m high. (Modified image of Espino-Barr *et al.*, 2012).

Scomberomorus sierra. From the Scombridae family and has a fusiform elongated body with pointed snout much shorter than the head, two dorsal fins. It has numerous rounded orange spots, in three rows under and over the lateral line (Collette, 1995) (Fig. 1). It is an epipelagic neritic species that inhabits coastal zones from 0 to 15 m depth (Robertson & Allen, 2008), it has a wide distribution in the Pacific, from United States of America to Perú, but has a limited capacity to migrate, compared to other bigger pelagic scombrids, due to its short pectoral fins and the density and length of its body (Manguson, 1978).

This species forms big shoals and feeds on small fish like a anchovy

and sardines, or crustaceans like shrimp (Collette, 1995; Espino-Barr *et al.,* 2004). Survival of their larvae is closely related to food availability (Shoji *et al.,* 2005), reason for which it spawns in zones near the coast(Collette, 1995) and in areas with high productivity.

According to the information of Arrival Reports (CONAPESCA, 2014), the catch reported annually in these two states is approximately of 239 tons (191 t in Jalisco and 48 t in Colima). According to CONAPESCA (2014), *S. sierra* is purchased from fishermen at minimum $8.00 MN per kg ($0.50 USD) to maximum $45.00 MN per kg ($2.50 USD), average $23.50 ($1.30 USD). This fishery is artisanal and uses gill nets and beach seine, and therefore it is fished with many other commercial species whose catch is incidental.

Espino-Barr *et al.* (2012) concluded that if the capture age is increased to 5.5 years, effort could increase four times resulting higher captures without negative consequences for the stock. Besides Espino-Barr *et al.* (2017) suggest two closed periods to the fishing: May and September.

In this study we describe the space-temporal variations in the coast of Jalisco and Colima (January 2003 to December 2013) with satellite compounds of CHLOa and NSST. The fishery production of *S. sierra* in the two states is analyzed using data of the Arrival Reports collected by Comisión Nacional de Pesca y Acuacultura (National Commission of Fishery and Aquaculture CONAPESCA). Also we associated the influence of NSST and CHLOa with the fishery production of *Scomberomorus sierra*.

Methods:
Regionalization of the study area. A polygon with coordinates was constructed based on the WGS 84 system (World Geodetic System 1984), where the exterior limit is a buffer area of 24 nm from the coast line .

Also, to limit the northern zone the maximum distance usually reached by small boats was marked (24 nm) assuming that it would leave from the most northern point of Jalisco (Fig. 2), while the southern limit was marked the same way, going south from the extreme of Colima. This way the northern limit was marked at 20.904°N and the southern at 18.282°N.

Fig. 2. Regionalization of the study area.

Obtaining data. Monthly compounds of NSST and CHLOa to scale of 1 km processed by CONABIO (2011) were obtained for 11 years (January 2003 to December 2013). The information of all the pixels (pxs) were obtained for the polygon of the previously regionalized study area using the SeaDAS© program, this procedure was done with each image.

Commercial capture data were obtained from the Arrival Reports in the Fisheries Office in Jalisco (Puerto Vallarta and Barra de Navidad) and Colima (Manzanillo and Tecomán).

Data management. To have a better understanding of the processes that occur in the study area, sub regionalization were carried out of the satellite components using the longitude and latitude values.

- By distance from the coast: this sub regionalization divided the polygon in four sections that go from 0 to 6 nm, 6 to 12 nm, 12-18 nm, and 18-24 nm. Using these new layers and using the program SeaDAS©, pixels from each sub region were identified.

- By latitude: all the values of the pixels coinciding with our study area were identified.

Once we had the different sub regions, we obtained the average of the pixels corresponding to each category.

Anomalies. To describe the annual variation, anomalies were calculated and plotted with the equation:

$$a = x_i - \bar{x}_m \qquad (eq. 1)$$

where: x_i = monthly average of the study area of CHLOa and NSST. In the case of the *S. sierra* capture, data are the sum of both states for each month. $\bar{x}_m$ = average of each month for 11 years (2003-2013).

Correlation. Since the exact point of capture cannot be obtained, correlations were carried out with data from both states (Jalisco and Colima) and the averages of NSST and CHLOa from the whole study area.

On the other hand, with the purpose of reducing the multiplicative effect observed in CHLOa, transformation of logarithms base 10 was made. Ortiz-Pinilla & Gil (2014) mention that the logarithms function is a strictly growing monotonous transformation, resulting in a transformed model equivalent to the original model. This guaranties an adequate interpretation of the coefficients with due care of the required transformations.

Subsequently, a moving average of 3 was calculated for the three variables (NSST, capture and CHLOa), with the equation 2.

$$Mo = \frac{x_{i-1} + x_i + x_{i+1}}{3} \qquad (eq. 2)$$

where: x_{i-1} = average of the variable obtained last month;

x_i = average of the variable obtained the current month;

x_{i+1} = average of the variable from next month. We should mention that the moving average reduces the list of cases, that is, the first and last values are lost (January 2003 and December 2013).

The normality assumption demanded by the correlation analysis was checked (Restrepo & González, 2007), using the Kolmogorov-Smirnov test (K-S test). This analysis compares the variable distribution with the normal distribution, measuring the maximum distance between both curves.

Pearson's correlation coefficient was used at an annual level; this coefficient measures the association degree between two quantitative variables, and is defined as:

$$r = \frac{s_{xy}}{s_y s_x} \qquad (eq. 3)$$

where: s_{xy} = covariance between two variables; s_x or s_y = standard deviation of each variable.
Later, to obtain the model significance values (p) a *t* Student test (α =0.05) was used:

$$t_c = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}} \qquad (eq. 4)$$

where: r = the result of the Pearson correlation; n = sample size.

Results:
Seasonal variation. Figure 3 shows the monthly average periods of the CHLOa, NSST and *S. sierra* capture from 2003 to 2013 considering the whole study area, and *figure 4* shows the monthly variation for each year, also for the whole area.

From February to April, the average of NSST had values lower than 25°C, in May and June, as it increases, a fast decrease in CHLOa concentration occurs, which ends in July and August, when a low average of the study area is registered with very low concentrations (<0.50 mg·m⁻³). In September a slight increase is observed, but it is until November when a constant increase can be identified in the whole area, completing the annual cycle. Therefore NSST and CHLOa show a seasonal pulse, repeated yearly, although in different intensity (Fig. 4).

CHLOa concentration shows a phase of rapid increment from November to January, culminating from February to April, which has a concentration higher than 3 mg·m^{-3}. In May and June CHLOa concentration decreases fast which ends in July and August, when a low average of the study area is registered with very low concentrations (<0.50 mg·m^{-3}). In September a slight increase is observed, but it is until November when a constant increase can be identified in the whole area, completing the annual cycle (Fig. 3). Therefore NSST and CHLOa show a seasonal pulse, repeated yearly, although in different intensity (Fig. 4).
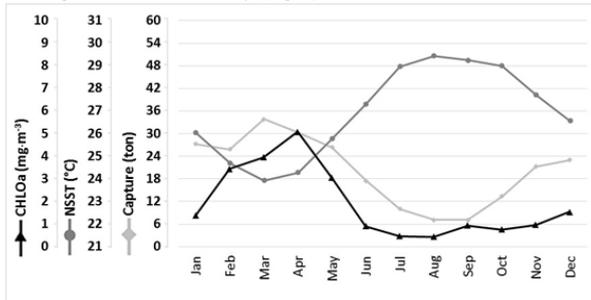
Fig. 3. Monthly average variation (2003-2013) of CHLOa, NSST and *Scomberomorus sierra* capture.
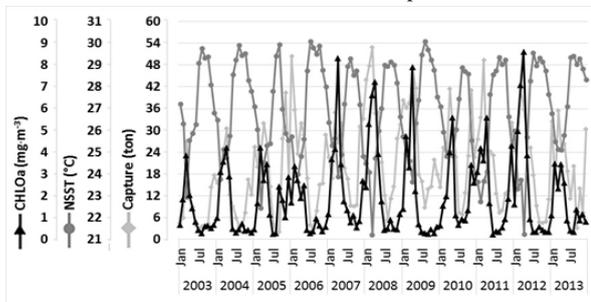
Fig. 4. Monthly average variation of CHLOa, NSST and *Scomberomorus sierra* capture from 2003 to 2013.

Distance of the coast and latitude variation. Figures 5 and 6 show graphics of the monthly average according to the latitude of NSST and CHLOa, respectively. This average considers all the years of study (2003-2013). Figure 7 shows yearly periodicity by averaging CHLOa and NSST in four different distances from the coast: 0-6 nm, 6-12 nm, 12-18 nm and 18-24 nm.

In the case of the NSST, February has an influence of the increase in intensity of the California Current and the upwelling begins to show in Banderas Bay (Fig. 5), which has its origin in the coast of Corrientes Cape; this sign shows as the intrusion of colder water (<23°C) close to the coast, approximately from 20.5° to 20°N, although the influence can extend more than 24 nm. During this month a coastal current is identified with direction from northwest-southeast on the continental platform (0 to 6 nm), transporting colder water from higher latitudes to lower, traveling the whole study area.

The Banderas Bay upwelling is present in most part of the study area in March, reducing even more the temperature. In April this trend is broken and the increase begins (Fig. 5), accelerating in May and June. At the same time these months maintain difference according to the distance to the coast; the closer (0-6 nm) is the colder (Fig. 6), especially in the area close to Corrientes Cape.

Reaching November the temperature comes down rapidly, and reaches values similar to those in June (Fig. 5), although in November the lower values are inside the Banderas Bay and zone near Corrientes Cape, while in June it is found in the region from 0 to 6 nm in the central-south coast of Jalisco and north Colima (Fig. 6).

The coastal current is observed with direction northwest to southeast, influencing all the area from 0 to 6 nm, carrying lower temperature water.

In December the temperature in Banderas Bay keeps decreasing showing values lower than 25°C, differently than the surrounding areas. This pattern is maintained until January, when the intensity of

the California Current increases and the temperature of the region homogenize with waters coming from higher latitudes. On the other hand these months (December and January) present important differences in latitude: at a higher, the temperature is lower by more than 2°C average between the northern and the southerner transect of the study area (Fig. 5).

Average values of CHLOa show that the sub region of 0 to 6 nm is the one that presents higher values and more variability during the whole year, contrary to the area from 18 to 24 nm, where values are lower and more stable (Fig. 7).

From February to May, with the presence of the upwelling, the concentration increases considerably, reaching a maximum in coverage and intensity in April. Besides in these months the differences in concentrations intensifies by the distance of the coast (Fig. 7), reaching 8 mg·m^{-3} differences in some areas between the sub region 0-6 nm and 18-24 nm.

Also in these months a latitudinal regionalization is observed, dividing the area in three big zones. The first one approximately from 20.788° to 20.464°N, where there is a considerable increment from 0 to 12 nm; this region belongs to the area of Banderas Bay. The second corresponds to a curve in the graph of latitude and concentration (Fig. 7) that extends from 20.266° to 19.727°N, with the highest values at 20.104°N. And the third region is proximately from 18.827° to 18.557°N. This region represents all the southern region of Colima to San Juan de Alima (Michoacán).
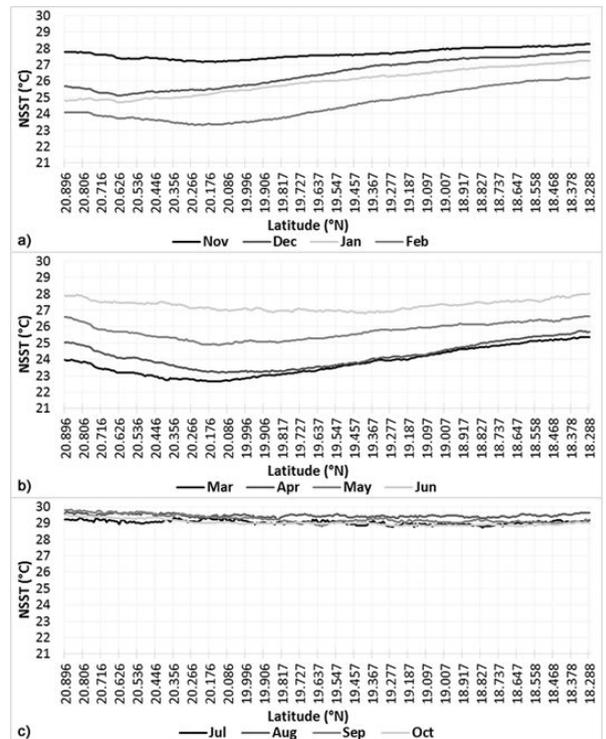
Fig. 5. Monthly average of nocturnal sea surface temperature (NSST) in different latitudes: a) March to June, b) July to October and, c) November to February.

The decrement of the CHLOa concentration begins in May, and in June this process is accelerated maintaining only the surrounding area to the coast and Banderas Bay with values higher than 1 mg·m^{-3} (Fig. 6). The CHLOa concentration reaches its lowest limit from July to October. Nevertheless July, August and September show three peaks in the concentration, which is in the sub region close to the coast from 0 to 6 nm (Fig. 6).

October shows a small descent in the concentration especially in Banderas Bay with a difference of 1 mg·m^{-3}, compared to the previous month, which is in line with the end of the rainy season in Jalisco.

From November to January the CHLOa concentration begins to increase as the NSST reduces, completing the yearly cycle (Fig. 7).
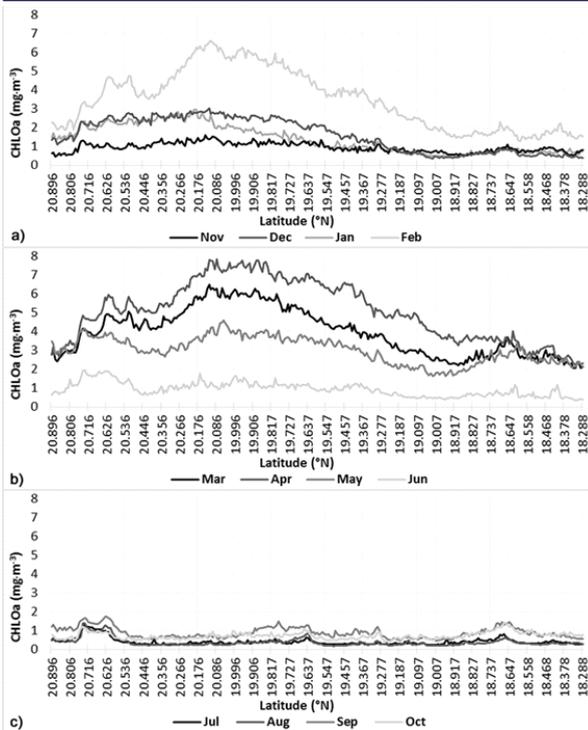
Fig. 6. Monthly average of chlorophyll *a* concentration (CHLOa) in different latitudes: a) March to June, b) July to October and, c) November to February.

Anomalies (2003 to 2013). Figure 8 shows monthly variations of the anomalies of a) CHLOa, b) NSST and c) capture of *S. sierra*. Maximum and minimum values of monthly and annual data of each variable are summarized in *Table 1* for the period of 2003 to 2013.

Most part of 2003 and 2014 show anomalies of NSST slightly higher and CHLOa concentration lower. This tendency does not change till the middle of 2005 when NSST has lower registers than the average in June, October and November, showing differences that reach 2°C; by contrast, an increment of the CHLOa concentration can be identified in September, October and December 2005 (Fig. 8).
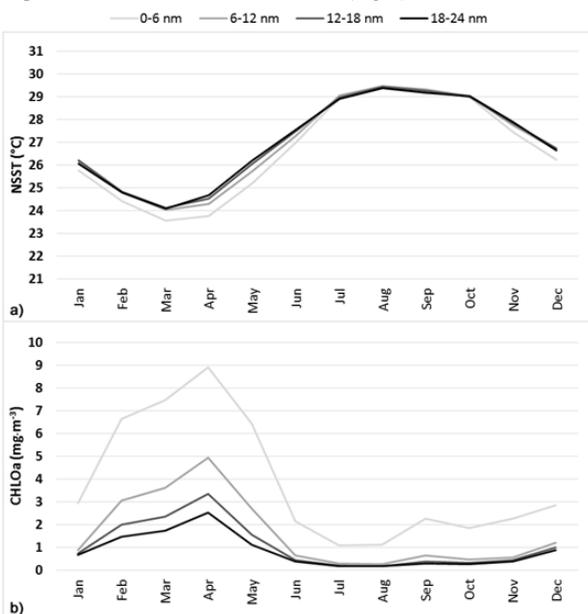
Fig. 7. Monthly variation of the average of chlorophyll *a* concentration (CHLOa) and nocturnal sea surface temperature (NSST) according to the distance from the coast.

In March 2006 an increase is registered in the anomalies of NSST that

end in March 2007. This covers most of the year including the summer months, and makes July 2006 the month with the highest NSST in the study area (30.09°C) in the 11 years this study covers. Besides the increments of the NSST anomalies there is an important decrease of the CHLOa concentration, showing an important reduction in April 2006 that reaches 3 mg·m⁻³.

In 2007 a slight increase of CHLOa concentration is observed in February and March, and higher in April, reaching a difference of 3.24 mg·m⁻³ compared to the average recorded for this month. At the same time an important decrease in the anomaly of NSST begins.

Both, the increment of CHLOa concentration and the decrease of NSST remain most of 2007, even till July 2008 (Fig. 8). This prolonged trend of CHLOa during the first months, situate 2008 as the year with the highest average of the concentration, together with March 2008, the lowest average of NSST in the area (21.2°C) during the 11 years of our study.

From July 2008 on, big differences are not observed in the anomalies, and this trend stands most of 2009, only February and April showed considerable increments of CHLOa concentration. Again, 2010 is a very irregular year; the first months have increments of NSST and decrease of CHLOa, till April. From May on, these anomalies are inverted, showing a decrease of NSST till December, with a difference of 2.7°C (Fig. 8), and inversely, CHLOa reaches its maximum in May, November and December.

These tendencies in the anomalies at the end of 2010 remain in January 2011, till May and June, where an increment of NSST occurred and a decrease of CHLOa, reason why June is identified as the month with the lowest average concentration (0.21 mg·m⁻³).

In November 2011 an increase in CHLOa is observed, which extends till February 2012 and increases even more in March and April, this anomaly causes April to be the month with the highest average concentration in the study area during 11 years (8.62 mg·m⁻³) (Fig. 8). These changes come with an anomalous reduction in NSST in February and April, this last month with a variation of 3.08°C respect the average. Most of the months from June 2012 on and till December 2013 have an increment of NSST, accompanied with a reduction of CHLOa concentration.

With regard to the capture of *S. sierra*, the first two years of this study register lower catches compared to the later years, even 2003, values have an important reduction from January to May, just in the highest season, whereas May of that year registered a production of only 9 tons, unlike the registered average of that month (26 t). Therefore 2003 is the year with less annual catch of these 11 years, with only 108 t (Fig. 8).

During 2004 the production of *S. sierra* remains below average, and although it exhibits an increase of 50 t, it still does not reach values of the following years. This tendency continues most of 2005 (January to August), even August has a capture of 1.5 t, placing it as the month with the lowest catch in 11 years, nevertheless October and November of that year register a considerable increase.

Next, 2006 presents registers close to the average, and with this trend the first half of 2007. However, at the end of 2007 and most of 2008 there is an important increase in captures, reaching a maximum difference of 21 t in February 2008 against average. The maximum capture in 11 years is reached in March 2008 (53 t) and it matches the increment in the CHLOa concentration. These series of increments in the high season (January-May) puts 2008 as the most productive year with 338 tons.

The first half of 2009 has an increment in the fishery production, reaching its maximum in April (17 t), the second half of the year also has increments but much lower.

In 2010 the increment is observed in October and has its effect on the variations of NSST and CHLOa, although these variations are present since June till December, different than the capture.

The anomalies in the years 2011 to 2013 are close to the average with just a few exceptions: March 2011 has an increment according to the average and reaches 15.6 t, but April has a reduction of 14.6 t. October,

November and December 2012 have a decline over 12 t of catch respect to the average of these months. August 2013 shows an increment of 13 t, but November has a reduction of 14 t compared to the average.

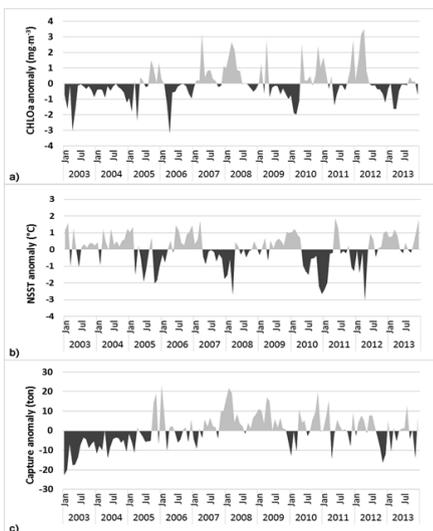**Table 1. Maximum and minimum values of the variables of chlorophyll *a* concentration (CHLOa), nocturnal sea surface temperature (NSST) and capture of *Scomberomorus sierra*.**

	CHLOa average	NSST average	*S. sierra* capture (ton)
Monthly maximum	2012, April 8.62 mg·m⁻³	2006, July 30.09°C	2008, March 53.014
Annual maximum	2008 2.59 mg·m⁻³	2013 27.46°C	2008 337.735
Monthly minimum	2011, June 0.21 mg·m⁻³	2008, March 21.19°C	2005, August 1.591
Annual minimum	2003 1.14 mg·m⁻³	2005 26.35°C	2003 108.170

Table 2. Correlations between variables (annual data): capture of *Scomberomorus sierra*, chlorophyll *a* concentration (CHLOa) and nocturnal sea surface temperature (NSST).

year	Capture *vs* CHLOa r^2	*p*	NSST *vs* captura r^2	*p*	NSST *vs* CHLOa r^2	*p*
2003	0.54	**0.01**	0.57	**0.01**	0.93	**< 0.01**
2004	0.65	**< 0.01**	0.87	**< 0.01**	0.85	**< 0.01**
2005	0.62	**< 0.01**	0.54	**0.01**	0.60	**< 0.01**
2006	**0.82**	**< 0.01**	0.89	**< 0.01**	0.94	**< 0.01**
2007	0.46	**0.01**	0.82	**< 0.01**	0.78	**< 0.01**
2008	**0.78**	**< 0.01**	0.94	**< 0.01**	0.92	**< 0.01**
2009	**0.98**	**< 0.01**	0.97	**< 0.01**	0.98	**< 0.01**
2010	**0.87**	**< 0.01**	0.71	**< 0.01**	0.71	**< 0.01**
2011	**0.74**	**< 0.01**	0.89	**< 0.01**	0.86	**< 0.01**
2012	**0.91**	**< 0.01**	0.88	**< 0.01**	0.96	**< 0.01**
2013	0.62	**< 0.01**	0.87	**< 0.01**	0.79	**< 0.01**

* Values with a relation r^2 higher than 70% are shown in bold numbers.
** Significant values of *p* in bold numbers.

Relationship between variables. Table 2 summarizes the results of the Pearson correlations (r^2) and its significance level (p). Likewise, *figure 9* shows the correlation variation according to the distance from the coast, of CHLOa and NSST with the capture of *S. sierra*.

In the coasts of Jalisco and Colima we identified that at lower NSST there exists an increment in the CHLOa concentrations, Pearson's correlation shows an inverse relationship between both variables, highly significant (Table 2). The year 2005 stands out because of its lower correlation (r^2<70%), probably because in September there is an increase of CHLOa, although the NSST remains over 29°C. We suggest that this increase in CHLOa is because of an external cause.

Fig. 8. Monthly variation of anomalies of a) chlorophyll *a* concentration (CHLOa), b) nocturnal sea surface temperature (NSST) and c) capture of *Scomberomorus sierra*.

We also found a significant relationship between CHLOa and the catch of *S. sierra*. There are years where this relation is higher than 80% as in 2006, 2009, 2010 and 2012. In other years, this relationship is lower as 2003-2007 and 2013, years identified by its low productivity of *S. sierra* capture (2003 and 2004) or by atypical increments of CHLOa (2005 and 2007).

These increments, although related to the increase of fish production, are not immediate; for example, the increment of CHLOa in 2005 starts after September, but it is till October-November when it is related to the increase of the fishing production, the same occurs with the rapid decrease of CHLOa in October and November, which is reflected in the capture data till December.

This same exercise was made with other areas by their distance from the coast (Fig. 9). In this case the correlation values are higher in the area of 18 to 24 nm during 2004 and 2007 and according to the total study area average, besides, in these same years plus 2010 and 2011, the area from 0 to 6 nm has lower values of this relationship.

In comparison, the catch also shows a close relationship with NSST (Table 2), in this case 2003 and 2005 have a lower correlation than the other years. It is probable that 2003 shows this irregularity due to the fact that the fishing production of *S. sierra* was very low. Surprisingly in 2004 where the relationship reached 87% with NSST, with CHLOa it was 65%. Also 2009 stands out because the fishing is correlated (97%) with NSST and 98% with CHLOa.
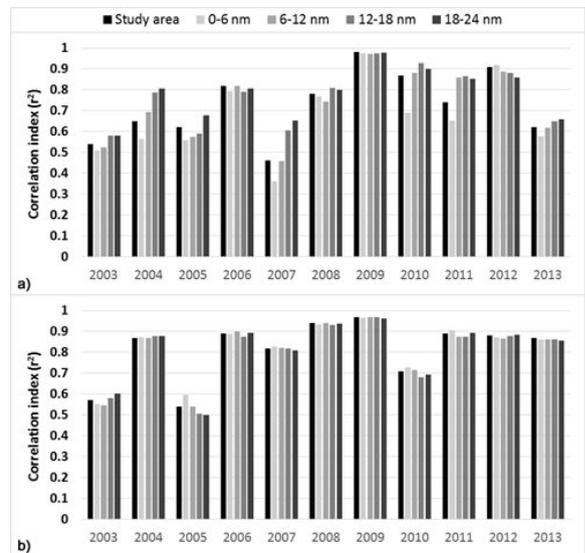

Fig. 9. Annual variation of Pearson's correlations index (r^2) of each distance from the coast, of the capture of *Scomberomorus sierra vs*: a) chlorophyll *a* concentration (CHLOa) and, b) nocturnal sea surface temperature (NSST).

El Niño influence in the study area. Table 3 shows values of the Pearson's correlations (r^2) and its significance (p) per year and per month between NSST anomalies and El Niño (ONI). Likewise, *figure 10* shows these two variables in monthly values for the period of this study (2003-2013).

Applying the correlation between the NSST anomalies data with the ONI, it was observed that the majority of the years present a significant correlation and the relationship is stronger (>%70) in the moderate years (of either Niño or Niña). In 2013 ONI presented values close to 0 most of the year, although NSST has an increment that does not coincide with the phenomenon.

The same analysis but monthly shows that in January and February, and from August to December have higher values of relationships, while from April to June these correlations are not significant.

Discussion:
Seasonal variation. At the beginning of the year the average of NSST in the study area shows values lower than 25°C because of three principal factors: 1) there is an increase of the California Current pushing water from higher latitudes, 2) it is related to this same

"push"with the abrupt changes in the bathymetry of Banderas Bay (Expósito-Díaz, 2004), which originates an upwelling of considerable magnitude, and 3) the reduction of the Equatorial Counter Current together with the Mexican Current (Wyrtki, 1965; Kessler, 2006)..

By contrast, from July to October the California Current loses force and Banderas Bay upwelling dissipates, and the intensity of the Equatorial Counter Current and the Mexican Current increase, causing a thrust of water from lower latitudes to higher, resulting in a mean temperature for the study area of around 29°C. The rest of the months show transitions between these two seasons: from November to January temperature descends while from May to June it increases.

Contrary to NSST, CHLOa concentration shows a phase of rapid increment from November to January related to the Banderas Bay upwelling, since the water flow of lower temperature, little oxygen and high quantity of nutrients are ideal for the phytoplankton increase in the area.

Espino-Barr *et al.* (2012) identified January to May and November to December as those that have higher production of *S. sierra*. We coincide with that temporality in both states, although Jalisco has higher captures and also variation in its registers, which go from 28.5 t of fish in March to 5.9 t in August.

Variations by the distance of the coast and the latitude. Although the variables' seasonality is present in the whole area, there is a differentiation in the response according to the distance of the coast and the latitude: the closer (0-6 nm) is the colder, especially in northern part of the study area.

The Banderas Bay upwelling is present in most part of the study area in March, but in April this trend is broken and temperature rises.

This latitudinal difference and the distance from the coast are due to the presence of the upwelling in Banderas Bay and the coastal current. Plotting this latitudinal variation of the NSST shows a characteristic curve that does not register in the posterior months. In July this increment ends, when the isotherm is reached and stays till October; these months of summer the coastal current cannot be seen in the NSST images.

In general it is observed that during the year there is an area from approximately 20.347° and 19.727°N that show important monthly variations of the temperature (≈2°C) from January to February, April to May, May to June, June to July, October to November and November to December.

The same occurs with CHLOa: the closer to the coast the higher its values, but also there is a marked latitudinal regionalization that can divide the study area into three: the northern (20.788° - 20.464°N) is the area of Banderas Bay; the middle (20.266° - 19.727°N) just south Corrientes Cape, with its influence extending south to the Cuyutlán lagoon. Probably this influence is as extensive due to the coastal current observed in the NSST. And the third region (18.827° - 18.557°N) is all the southern region of Colima to San Juan de Alima (Michoacán).

Table 3. Yearly and monthly correlations between the nocturnal sea surface temperature (NSST) anomalies and oceanic El Niño index (ONI).

Year	n	r²	p	Month	n	r²	P
2003	11	**0.65**	**<0.01**	January	10	**0.69**	**<0.01**
2004	12	0.17	0.19	Febr uary	11	**0.63**	**<0.01**
2005	12	0.47	**0.01**	March	11	0.48	**0.02**
2006	12	**0.76**	**<0.01**	April	11	0.04	0.55
2007	12	**0.81**	**<0.01**	May	11	0.03	0.62
2008	12	**0.69**	**<0.01**	June	11	0.06	0.48
2009	12	**0.78**	**<0.01**	July	11	0.37	**0.05**
2010	12	**0.79**	**<0.01**	August	11	**0.82**	**<0.01**
2011	12	**0.88**	**<0.01**	September	11	**0.62**	**<0.01**
2012	12	0.44	**0.02**	October	11	**0.62**	**<0.01**
2013	11	0.35	0.06	November	11	**0.61**	**<0.01**
				December	10	**0.68**	**<0.01**

* Values of r^2 with a relation higher than 60% are shown in bold numbers.
** Significant values of p in bold numbers.

With the increase in intensity of the Mexican Current fed by the Equatorial Counter Current and the isotherm formation of the area, the CHLOa concentration reaches its lowest limit from July to October; increments occur from July to September, related to zones of epicontinental water bodies, and months of rainy season in these states, therefore these increments are associated to the haulage of organic matter; the monthly increments are till September, and the concentration is higher than 3 mg·m⁻³. At the end of the rainy season this concentration decreases.

In contrast, the lack of knowledge of where *S. sierra* was fished prevents the use of a precise regionalization and forced us to analyze at a state level as the minimum scale. For this reason it is impossible to determine whether there is a distance variation of the coast or a latitudinal regionalization of its abundance.

Coastal waters of the Pacific Ocean surrounding Jalisco and Colima are very productive. The upper superficial layer to a depth of approximately 50-75 m is occupied by water with high temperature and salinity (Filonov et al., 2000). During summer, coastal flow pass through from south, originated by the penetration of the North Equatorial Counter Current (Burkov, 1972; de la Lanza, 1991; Badan, 1997).

The continental platform in this region is very narrow, 7 to 10 km considering the 200 m isobaths. The water dynamics is determined by an average flow with northwest direction during the summer months, and in the opposite direction in winter (De la Lanza, 1991; Badan, 1997). There is also a barotropic tide that originates oscillations of the sea level in the lagoon of Barra de Navidad of maximum 1.2 m (Filonov *et al.*, 2000).
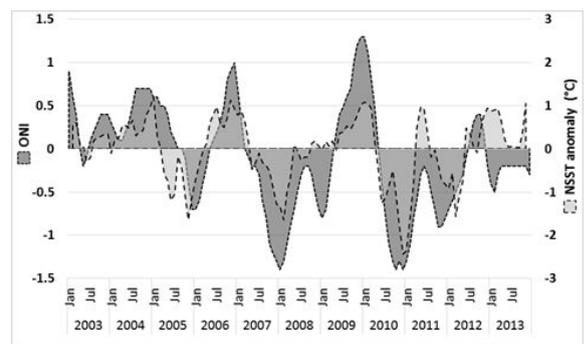

Fig. 10. Monthly variations of the oceanic El Niño index (ONI) and nocturnal sea surface temperature (NSST).

We consider important the fact that the marine circulation phenomenon in the study area of Jalisco and Colima are influenced by a dynamic related to the tropical Pacific Ocean temperature, and at a higher scale to what happens in the Dome of Costa Rica, the Gulf of Tehuantepec and the North Equatorial countercurrent system, which are strongly induced by wind regime of Central America mountain range(Kessler, 2006).

Inter annual variability of the marine surface temperature suggest that the force of this North Equatorial countercurrent system in central Pacific during the Niño events continue throughout the coast increasing the sea surface temperature by zonal advection (Kessler, 2006), so the annual cycle of the Costa Rican Dome should not be seen as an isolated phenomenon. Future research will allow a better understanding of these phenomena and their variability.

Anomalies (2003-2013). The study of the anomalies of any variable gives a different insight to its behavior. Although there is a periodical component in our three variables, there are changes that stand out.

The increment of CHLOa concentration and the decrease of NSST remained most of 2007 and till July 2008, which situate this period as the one with the highest average of CHLOa and the least average of NSST in the area (21.2°C) during the 11 years of our study.

Also, at the end of 2010 and till June, there were very irregular months with high values of NSST and decrease of CHLOa. June is identified as the month with the lowest average concentration (0.21 mg·m⁻³).

Filonov *et al.* (2000) conclude that the anomalies of superficial temperature during the Niño year in the equatorial region of the Pacific during 1995 and 1996 were "normal", but in 1997 these anomalies increased strongly and in December they reached 4°C above.

Olivos-Ortiz *et al.* (2016) described the Central Mexican Pacific as a zone where two systems confluence: firstly governed by an oceanic circulation of the California Current that flows south in winter and spring, and the influence of tropical waters that conform the Mexican Coastal Current flowing north during summer and autumn (Filonov *et al.*, 2000; Torres-Orozco *et al.*, 2005). Both make this region a transition zone where tropical storms and Niño-Niña phenomena are present, which reflect in the coastal zone of Jalisco and Michoacán in a narrow continental platform of 5 to 12 km (Filonov *et al.*, 2000; Lavín *et al.*, 2006). In these area harmful algae blooms occur. Olivos-Ortiz *et al.* (2016) analyzed results from 2009 to 2013 from the coast of Corrientes Cape, Jalisco to Maruata, Michoacán, with special emphasis in the state of Colima. The harmful algae blooms occur between March and May or October and November mainly in Corrientes Cape and Boca de Apiza, Michoacán. The dominant groups were diatoms during April and October 2010, and dinoflagellates during 2011 and June 2012. These proliferations can occur even when there are no nutrimental inputs of the rivers, but the upwelling areas that tend to be intense.

The oceanic region studied by Olivos-Ortiz *et al.* (2016), although 80 km away from the coast, presented CHLOa ranging from 0.01 to 2.5 mg·m^{-3}. Also high values were present between March-May and June-August, associated to the presence of cyclonic turns with concentrations up to 18 mg·m^{-3} at 0 m in the central oceanic region of the study zone and in front of Michoacán. Close to the coast, averages were of 2.50, 0.82 and 1.28 mg·m^{-3} during January, March-June and October, respectively. Maximum values appeared during the cold water pulses between May-June which generated 12.86 mg·m^{-3} off Punta Pérula, Jalisco. This high primary productivity spread south to Manzanillo Bay where 8.2 mg·m^{-3} was detected during the same months. Values up to 12.3 mg·m^{-3} were observed between October-November in Boca de Apiza, Michoacán. Values along the coastal zone were statistically different (p=0.03) between Corrientes Cape and Punta Pérula, Jalisco and Boca de Apiza, Michoacán, compared to the rest of the sampling sites.

Gómez-Villareal *et al.* (2008) also found harmful algae proliferations during 2000 and 2001 in Banderas Bay, between Punta de Mita, Nayarit and south of Corrientes Cape, Jalisco. The highest values of satellite chlorophyll in 2000 and 2001 were present from February to May, while lower concentrations were in July to October except August 2000.

Proliferations during winter-spring were multispecies, favored by high levels of chlorophyll, while in summer-autumn were dominated by only one species of a highly toxic dinoflagellate, *Cochlodinium polykrikoides* (Margalef, 1961; Cortés-Lara *et al.*, 2004). These proliferations were favored by the effect of other previous algae, as for other local conditions.

Relationship between variables. There were important significant relationship between CHLOa and NSST which were described with the maps, numerically confirmed. Statistically significant relationships were also obtained with information of the fishery.

In some cases these relationships, although related to the increase of fish capture decrease, were not immediate; for example, the increment of CHLOa in 2005 starts after September, but it is till October-November when it is related to the increase of the capture. Also with the rapid decrease of CHLOa in October and November, it shows in the capture of December. Espino-Barr *et al.* (2008) found a better relation with crossed correlation between the presence of the snapper and the El Niño multivariate index, which means that the effect of the climate is not immediate; depending on the species is the temporality of the relationship.

Also, according to the distance from the coast, a relationship was found with the fishery; this species tends to stay close to the coast (Allen &

Robertson, 1994). In this sense, a higher value of CHLOa shows better conditions for a higher capture of *S. sierra*. According to this criterion, it would be expected that the area 0 to 6 nm would have a closer relationship, given that it is the area with higher concentration. Nevertheless we observed that in 8 years the area from 18 to 24 nm had higher relationship values. It is possible that the reason for this variation is that at a given point a larger amount of CHLOa in the region is not necessarily reflected in a larger *S. sierra* catch, because there are other factors that influence the maximum capture that a fisherman can obtain, for example biological factors as the inter or intra specific relation (competence and predation), besides *S. sierra* is not a species that feeds on phytoplankton, but follows sardines and anchovies (Allen & Robertson, 1994).

The results using values of the areas of different distance from the coast did not show substantial changes between the different regions. The reason for the lack of differentiation between areas is due to the fact that, although there are variations according to the distance to the coast by the coastal current, the main changes are given by latitude depending on the presence or absence of the upwelling of Banderas Bay. It could be expected that this area had higher captures, but with annual data there is no way to differentiate the exact site to allow us to check this.

El Niño influence in the study area. Most relationships between anomalies of NSST and ONI occur in January, February and from August to December, due to the influence of the Mexican Current and the Equatorial Counter Current. These currents are affected directly by the trade winds that circulate from 0° to 30° latitude, and in the northern hemisphere have a northeast-southwest direction. In a warm phase El Niño is identified by the reduction in intensity of these winds, causing a decrease of the thermocline, which in turn triggers a warming of the sea surface in the eastern equatorial Pacific Ocean.

Wang & Fiedler (2006) found that the highest temperatures of the eastern tropical Pacific occur from January to March the year after the wind anomalies during Niño year, as a suppression of the cold phase of the annual cycle. The mechanisms of water heating have been studied locally, therefore Wyrtki (1974, 1975) used time series of the sea level in the islands and coasts, and its relationship with the eastern thermoclines that allow the heating of the waters, besides considering the wind regime.

This new type of approach helps to explain the Niño events, considering the water dynamics from Perú, passing by the Costa Rican Dome and the Gulf of Tehuantepec, where diverse currents and countercurrents play a primary role, as evidenced by the increasing penetration of tropical waters into the Gulf of California associated with the Niño events (Baumgartner & Christensen, 1985, Filonov & Tereshchenko, 1999; Lavin *et al.*, 2003). Barberan *et al.* (1984) explained the normal conditions in the Costa Rican Dome during 1979 and its changes in the Niño year of 1982 with and an increase of the deep isotherms.

Fishery and Scomberomorus sierra parameters. Domínguez-López *et al.* (2010) found a high mitochondrial genetic diversity and a high divergence of *S. sierra* in the coast of the Pacific. They found two genetically different groups: one in the northern area in the coasts of Sinaloa and a second group in the central area of Michoacán, Oaxaca and Chiapas. These authors think that there is a third group in Perú with a few genetic differences. The existence of natural barriers could explain their confinement to certain areas, also the asynchronous spawning that isolate the stocks and form diverse stocks genetically different (Shoji *et al.*, 2005).

Nava-Ortega *et al.* (2012) reported important differences in the population parameters of *S. sierra* (Table 4), which reach bigger lengths at the same age in Mazatlán than in the coast of Jalisco and Colima, this strengthens the idea that it could be about different populations of *S. sierra*: the one that appears in the Gulf of California (Sinaloa) with respect to the one in the Mexican Central Pacific (Jalisco-Colima). Zárate-Becerra & Nava-Ortega (2016) studied biological parameters of *S. sierra* in three seasons (Table 4) and found an exploitation rate of E = 0.80.

Table 4. Population parameters of *Scomberomorus sierra* in the central Mexican Pacific (Jalisco-Colima) and its differences with other studies (modified from Nava-Ortega et al., 2012).

	Espino-Barr *et al.* (1990)	Aguirre-Villaseñor *et al.* (2006)	Nava-Ortega *et al.* (2012)	Nava-Ortega *et al.* (2012)	Zárate-Becerra & Nava-Ortega (2016)
Area	Colima, México	Gulf of California (Sinaloa)	Central Mexican Pacific	Central Mexican Pacific	Nayarit, México
Method	Total length (ELEFAN)	Furcal length	Total length (ELEFAN)	Total length (otoliths)	Total length (length frequency)
L_∞ (cm)	96.51	108.30	95.50	99.54	103-108
k	0.360	0.150	0.207	0.205	0.186-0.260
t_0	-0.023	0.0001	0.019	-0.060	-0.0134 - 0.00007
Longevity (years)	8	20	14	15	16
Φ' (phi')	3.525	3.245	3.276	3.308	3.33-3.47
Temperature (°C)	26.5		26.5	26.5	
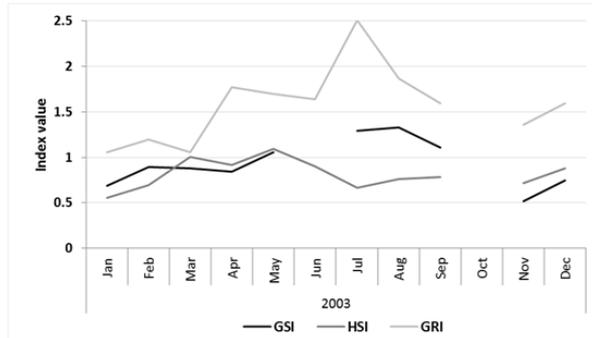
Fig. 11. Monthly variations of gonadosomatic index (GSI), hepatosomatic index (HSI) and gastric repletion index (GRI) of *Scomberomorus sierra* (modified from Espino-Barr *et al.*, 2017).

During 2003 three periods in the biology of *S. sierra* were observed: the first from January to May, which are months when the CHLOa concentration increases and NSST decreases in the study area, the upwelling in Banderas Bay is present and is an abundance time in which according to Espino-Barr *et al.* (2017) *S. sierra* presents the highest values of the HSI and an increment in the GSI and GRI (Fig. 11). During this period the first massive spawning occurs (Espino-Barr *et al.,* 2017) and the presence of this species increases in all the study area, so the capture values are high.

The second period is from June to August, when an increment of the average NSST and a decrement of CHLOa occurs, the upwelling of Banderas Bay disappears, and the rainy season together with tributaries transport organic matter into the sea, causing high concentrations of CHLOa (>2 mg·m^{-3}) in the area close to the coast, as observed in Banderas Bay and Mismaloya Beach. Therefore, possibly in this period the species is confined to these areas maintaining adequate feeding conditions for larvae, juveniles and adults. Also, a second period of massive spawning is developed. Also in July higher values of GSI and GRI are reached (Espino-Barr *et al.,* 2017). Therefore because of this confinement, *S. sierra*'s presence diminishes in all the study area and is reflected directly as the lowest captures.

A third period occurs from September to December, as a negative slope in the rainy season, the first months ending in Jalisco and then in Colima. In November and December NSST starts descending and CHLOa increases in the study area, followed by increments in the values of GSI, GRI and HIS reported by Espino-Barr *et al.* (2017) (Fig. 11). It is likely that the species having food throughout the area and not only in particular zones have a greater presence in the region, which reflects directly in the increase of the catches.

Conclusions:
Both NSST and CHLOa show differences in the area of Banderas Bay from February to May due to the upwelling in this region.

CHLOa reaches its maximum values from 0 to 6 nm from the coast and from 18 to 24 nm, values are the lowest and stable.

There are important inter-annual variations, with an increment in the CHLOa concentration in September and October, and lower values of

NSST in June, July and November.
The highest annual average value of CHLOa occurred in 2008 (2.59 mg·m^{-3}) and the lowest in 2003 (1.14 mg·m^{-3}).

The highest annual average register of NSST occurred in 2013 (27.46°C), and the lowest in 2005 (26.35°C).

A strong inverse relationship ($r^2>0.70$) and highly significant ($p<0.01$) was observed in the CHLOa concentration and NSST, except in 2005, when this relationship ($r^2<0.70$) was the lowest.

The influence of the ENSO phenomenon was identified in summer when the Mexican Current and the Equatorial Counter Current have a higher presence in the study area.

Jalisco has higher catches of *S. sierra* than Colima, and also higher variations from 28.5 t in March to 5.9 t in August.

The higher captures of *S. sierra* in Jalisco and Colima take place from January to May and secondly from November to December.

The lowest capture of *S. sierra* took place in 2003 and the highest in 2008.

The highest monthly register was in March 2008 coinciding with high values in the CHLOa concentrations and the lowest in August 2005.

The highest correlation years ($r^2 >0.80$) between CHLOa and capture of *S. sierra* were in 2006, 2009, 2011 and 2012, and the lowest ($r^2 <0.70$) in 2003, 2004, 2005, 2007 and 2013.

Some increments in the CHLOa concentration do not manifest immediately in captures, like the case of 2005, when they were set off by one month.

In general there is a strong inverse relationship ($r^2 >0.70$) between NSST and *S. sierra* capture, however there are low values ($r^2<0.70$) in 2003 and 2005.

During 2003 three periods were identified in the distribution and reproduction of *S. sierra*:
1. From January to May, high values of CHLOa concentrations and low NSST, coinciding with high values of the gonadosomatic (GSI), the hepatosomatic (HIS) and gastric repletion (GRI) indexes, also high values of capture of *S. sierra* are shown.
2. From June to September high values of GSI and GRI are found, although it is possible that the species hides away in areas where high values of CHLOa concentrations are found, thanks to the organic matter flow, therefore a drastic reduction of captures was obtained.
3. From October to December, the CHLOa concentration increases again and NSST decreases in the area, there is a rise in captures and the GSI, HSI and GRI also increment, but do not reach the values of the first two periods.

Recommendations:
1. It is important that more studies are done in relation to the influence of the California Current in the coast of Mexican Pacific in general and in the states of Jalisco and Colima in specific. To this day it has been reported that waters of the California Current do not reach the coasts of the Central Mexican Pacific

(Hernández-Contreras, 2016) due to its density, so what could be happening Is that this current is only pushing waters of higher latitudes, but of the same water masses. A higher number of studies and publications would help to understand this phenomenon with more clarity.

2. A closer work has to be done with the fishing cooperatives to know where fishermen obtain their product and its seasonality, to know more precisely the distribution and abundance of the species submitted to commercial catch and its relation to NSST and CHLOa.

3. Continue with the population dynamics study of the species commercially used, to know other additive factors (growth and recruitment) and subtractive (natural and fishing mortality) for long time series, to be able to use models of maximum sustainable yield, simulation and prediction of captures.

4. Continue with the remote perception analysis to determine CHLOa and NSST parallel to the population parameters of the commercially important species.

5. Develop studies to know the transition areas in the coast of the Mexican Pacific in general and particularly the states of Jalisco and Colima.

6. Avoid the destruction of mangroves that endanger the extinction of species, for being areas of feeding and growing.

7. Prevent the contamination of the zones close to the coast that cause high values of mortality by poisoning of organisms.

References:

[1] Allen, G.R., Robertson, D.R. (1994). *Peces del Pacífico Oriental Tropical*. CONABIO, Agrupación Sierra Madre Y CEMEX, 327.

[2] Aguirre-Villaseñor, H., Morales-Bojórquez, E., Morán-Angulo, R.E., Madrid-Vera, J., Valdez-Pineda, M.C. (2006). Biological indicators for the Pacific sierra (*Scomberomorus sierra*) fishery in the southern Gulf of California, Mexico. *Ciencias Marinas* 32(3): 471-484.

[3] Badan, A. (1997). La Corriente Costera de Costa Rica en el Pacífico Mexicano. *In:* M.F. Lavín (Ed.), *Contribuciones a la Oceanografía Física en México.* (pp. 99–112). Monografía No. 3, Unión Geofísica Mexicana.

[4] Barberan, J., Gallegos, A., Padilla, A.R. (1984). The Costa Rica Dome during the onset of the 1982–83 El Niño. *Tropical Ocean- Atmosphere Newsletter* 24: 13-14.

[5] Baumgartner, T.R., Christensen, N. (1985). Coupling of the Gulf of California to large-scale interannual climate variability. *Journal of Marne Research* 43: 825-848.

[6] Burkov, V.A. (1972). *The General Circulation of the Pacific Ocean*. Nauka, Moscow.

[7] Collette, B.B. (1995). Familia: Scombridae. *In:* W. Fischer, F. Krupp, W. Schneider, C. Sommer, K.E. Carpenter, V.H. Niem (Eds.). *Guía FAO para la identifiacación de especies para los fines de Pesca, Pacífico Centro-Oriental*. FAO, Roma.

[8] CONABIO. (2011). Sistema Satelital de Monitoreo Océanico (SATMO). Retrieved September 9, 2017, from http://www.biodiversidad.gob.mx/pais/mares/satmo/

[9] CONABIO. (2012). Portal de Geoinformación, Sistema Nacional de Información Sobre la Diversidad. Retrieved September 7, 2017, from http://www.conabio.gob.mx/informacion/gis/

[10] CONAPESCA. (2014). Avisos. Retrieved September 9, 2017, from http://www.conapesca.gob.mx/wb/cona/cona_avisos

[11] Cortés-Lara, M.C., Cortés-Altamirano, R., Sierra-Beltrán, A.P. (2004). Presencia de *Cochlodinium catenatum* (Gymnodiniales: Gymnodiniaceae) en mareas rojas de Bahía de Banderas, Pacífico Mexicano. *Revista de Biología Tropical* 52: 35-49.

[12] De la Lanza, G.E. (1991). *Oceanografia de Mares Mexicanos*. AGT Editor.

[13] Domínguez-López, M., Uribe-Alcocer, M., Díaz-Jaimes, P. (2010). Phylogeography and historical demography of the Pacific Sierra mackerel (*Scomberomorus sierra*) in the Eastern Pacific. *BMC Genetics* 11: 34, 12.

[14] Espino-Barr, E., Cruz-Romero, M., Garcia-Boa, A. (1990). Biología pesquera de tres especies de la familia Scombridae en el litoral de Colima, México. 65-74. *In:* Dailey, M. & Bertsch H. (Ed.). *Memorias del VIII Simposium de Biología Marina*. Ensenada, México.

[15] Espino-Barr, E., Cabral-Solís, E.G., Garcia-Boa, A., Puente-Gómez, M. (2004). *Especies marinas con valor comercial de la costa de Jalisco*. México: INP-SAGARPA.

[16] Espino-Barr, E., Garcia-Boa, A., Cabral-Solís, E.G., Puente-Gómez, M. (2008). *Pesca artesanal multiespecífica de la costa de Colima. Criterios biológicos para su administración.* Linderos de la Costa. Centro Interdisciplinario de Investigaciones en Medio Ambiente y Desarrollo, IPN.

[17] Espino-Barr, E., Nava-Ortega, R.A., Gallardo-Cabello, M., Cabral-Solís, E.G., Puente-Gómez, M., García-Boa, A. (2012). Aspects of *Scomberomorus sierra* fishery from the coast of Colima, México. *Ciencia Pesquera* 20(1): 77-88.

[18] Espino-Barr, E., Gallardo-Cabello, M., Nava-Ortega, R.A., Puente-Gómez, M., Garcia-Boa, A. (2017). Reproduction of *Scomberomorus sierra* (Percoidei:Scombridae) in the Central Mexican Pacific Coast. *Revista de Investigación Agropecuaria* 21(1): 47-64.

[19] Expósito-Díaz, G. (2004). Reporte batimétrico de Bahía de Banderas, como parte de la campaña: Estudio Prospectivo Oceanográfico frente a las Costas del Pacífico Central Mexicano (PROCEAM-2004). Informe interno del curso: Métodos de Investigación Oceanográfica, Semestre: 2004-2. UNAM, 9.

[20] Filonov, A.E., Tereshchenko, I.E. (1999) El Niño 1997-98 monitoring in mixed layer at the Pacific Ocean near Mexico's west coast. *Geophysical Research Letters* 27: 705-707.

[21] Filonov, A.E., Tereshchenko, I.E., Monzón, C.O., González Ruelas, M.E., Godínez Domínguez, E. (2000). Variabilidad estacional de los campos de temperatura y salinidad en la zona costera de los estados de Jalisco y Colima, México. *Ciencias Marinas* 26(2): 303-321.

[22] Gallegos, A., Rodríguez, R., Márquez, E., Lecuanda, R., Zavala-Hidalgo, J. (2006). Oceanografía física: Una climatología de la temperatura de la superficie del mar de las aguas adyacentes a las costas de Jalisco, Colima y Michoacán, México: 1996-2003. In: M. C. Jiménez-Quiroz & E. Espino-Barr (Eds.). *Los recursos pesqueros y acuícolas de Jalisco, Colima y Michoacán.* (pp. 17–28). SAGARPA, Instituto Nacional de la Pesca.

[23] Gómez-Villarreal, M.C., Martínez-Gaxiola, M.D., Peña-Manjarrez, J.L. (2008). Proliferaciones algales 2000–2001 en Bahía de Banderas, México según el sensor SeaWiFS. *Revista de Biología Tropical* 56(4): 1653-1664.

[24] Hernández-Contreras, R.E. (2016). Detección de la variabilidad de la salinidad superficial del sistema de Corriente de California mediante datos del sensor AQUARIUS y su relación con fenómenos de macroescala (2011 a 2015). Posgrado en Ciencias del Mar y Limnología, UNAM.

[25] INEGI. (2010). Actividades económicas primarias, pesca. Retrieved September 9, 2017, from http://cuentame.inegi.org.mx/economia/primarias/pesca/

[26] Kessler, W.S. (2006). The circulation of the eastern tropical Pacific: A review. *Progress in Oeanography* 69: 181-217.

[27] Lavín, M.F., Palacios-Hernández, E., Cabrea, C. (2003) Sea surface temperature anomalies in the Gulf of California. *Geofísica Internacional* 42: 363-375.

[28] Lavín, M.F., Fiedler, P.C., Amador, J.A., Ballance, L.T., Färber-Lorda, J., Mestas-Núñez, A.M. (2006). A review of eastern tropical Pacific oceanography: Summary. *Progress in Oeanography* 69(2-4): 391-398.

[29] Manguson, J.J. (1978). Locomotion by scombrid fishes. *In:* W.S. Hoar, D.J. Randall (Eds.), *Fish Physiology Volume VII* (pp. 239–313). New York: Academic Press.

[30] Margalef, R. (1961). Hidrografía y fitoplancton de un área marina de la costa meridional de Puerto Rico. *Investigación Pesquera* 18(1): 33-96.

[31] Nava-Ortega, R.A., Espino-Barr, E., Gallardo-Cabello, M., Garcia-Boa, A., Puente-Gómez, M., Cabral-Solís, E.G. (2012). Growth analysis of the Pacific sierra *Scomberomorus sierra* in Colima, México. *Revista de Biología Marina y Oceanografía* 47(2): 273-281.

[32] NOAA. (2014). *El Niño & La Niña (El Niño-Southern Oscillation)*. Retrieved August 8, 2017, from https://www.climate.gov/enso

[33] Olivos-Ortiz, A., Quijano-Scheggia, S.I., Perez-Morales, A., Gaviño-Rodríguez, J.H., Kono-Martínez, T., Pelayo-Martínez, G.C., Ortega-Ortiz, C.D., Verduzco-Zapata, M.G. (2016). Condiciones hidrográficas en el Pacífico Central Mexicano relacionadas con florecimientos algales en la zona costera de Colima. *In:* E. García-Mendoza, S.I. Quijano-Scheggia, A. Olivos-Ortiz, E.J. Núñez-Vázquez (Eds.), *Florecimientos algales nocivos en México* (pp. 256–267). Ensenada, México.: CICESE.

[34] Ortiz-Pinilla, J., Gil, D. (2014). Transformaciones logarítmicas en regresión simple. *Comunicaciones en Estadística* 7 (1): 89-98.

[35] Restrepo, L.F., González, J. (2007). De Pearson a Spearman. *Rev. Col. Cienc. Pec.* 20: 183-192.

[36] Robertson, D.R., Allen, G.R. (2008). *Peces Costeros del Pacífico Oriental Tropical: Sistema de Información en línea. Versión 1.0*. Retrieved August 8, 2017, from http://biogeodb.stri.si.edu/sftep/es/thefishes/species/2215

[37] Ruiz-Durá, M.F. (1985). *Recursos Pesqueros de las Costas de México*. (2da ed.). México, D.F., Limusa.

[38] Shoji, J., Tstomu, M., Tanaka, M. (2005). Larval growth and mortality of Japanese Spanish Mackerel (*Scomberomorus niphonius*) in the central Seto Inland Sea, Japan. *Journal Marine Biology Association of Th United Kingdom* 85: 1255-1261.

[39] Torres-Orozco, E., Trasviña, A., Muhlia-Melo, A., Ortega-García, S. (2005). Mesoscale dynamics and yellowfin tuna catches in the Mexican Pacific. *Ciencias Marinas* 31(4): 671-683.

[40] Wang, C., Fiedler, P.C. (2006). ENSO variability in the eastern tropical Pacific: a review. *Progress in Oceanography* 69 (2-4): 239-266.

[41] Wyrtki, K. (1965). Surface currents of the eastern Pacific Ocean. *Bull. Interam. Trop. Tuna Comm.* 9: 279-303.

[42] Wyrtki, K. (1974). Equatorial currents in the Pacific 1950 to 1970 and their relation to the trade winds. *Journal of Physical Oceanography* 4: 372-380.

[43] Wyrtki, K. (1975). Fluctuations of the dynamic topography in the Pacific Ocean. *Journal of Physical Oceanography* 5: 450-459.

[44] Zárate-Becerra, M.E., Nava-Ortega, R.A. (2016) Parámetros biológicos de *Scomberomorus sierra* en Nayarit, comparación entre las temporadas 2009, 2010 y 2011. *Ciencia Pesquera* 24(2): 41-51.