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LOBSTER (*PANULIRUS ARGUS*) CAPTURES AND THEIR RELATION WITH ENVIRONMENTAL VARIABLES OBTAINED BY ORBITAL SENSORS FOR CUBAN WATERS (1997-2005)

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LOBSTER CAPTURES AND ENVIRONMENTAL VARIABLES

ABSTRACT

Chlorophyll concentrations (Chl-a) data obtained from the Sea Viewing Wide Field of View Sensor (SeaWIFS) ocean color monthly images, Sea Surface Temperature (SST) pathfinder data obtained from the Advanced Very High Resolution Radiometer (AVHRR) sensors, and lobster (*Panulirus argus*) captures at the Cuban shelf were examined in order to analyze their spatial and temporal variability. A cross-correlation analysis was realized between the standardized anomalies of the environmental variables (Chl-a and SST) and the standardized anomalies of lobster captures for each fishery zones for the period between 1997 and 2005. For the deep waters adjacent to the fishing zones it was not observed a clear Chl-a seasonality and on average the lowest values occurred south of the Island. It is with the three years lag that Chl-a had the greatest numbers of significant correlation coefficients for almost all fishing zones. However, the cross-correlation coefficients with SST showed higher values with 1,5 year lag at all zones. Since the two environmental variables obtained by satellite sensors (SST and Chlo-a) influence the lobsters mainly during the planktonic life cycle, the cross-correlation with lobster captures begin to show significant indexes with lags of 1,5 years or more.

Descriptors: *chlorophyll-a, sea surface temperature, lobster captures, cross-correlation.*

RESUMO

Dados de captura de lagosta *Panulirus argus* na plataforma cubana foram comparados com concentrações de clorofila (Chl-a) e valores de Temperatura de Superfície do Mar (TSM) obtidos pelos sensores *Sea Viewing Wide Field of view Sensor* (SeaWIFS) e *Advanced Very High Resolution Radiometer* (AVHRR), respectivamente. Uma análise de correlação cruzada foi realizada entre as anomalias padronizadas das variáveis ambientais (Chl-a e TSM) e as anomalias padronizadas de capturas da lagosta para cada zona de pesca no período 1997-2005. Para as águas profundas adjacentes às zonas de pesca não foi observada uma sazonalidade evidente da Chl-a. De forma geral, os menores valores de Chl-a ocorreram ao lado sul da Ilha. Na maioria das zonas de pesca, a captura da lagosta teve os maiores coeficientes de correlação com valores de Chl-a com defasagem de dois e três anos. Já em relação à análise com dados de TSM, os coeficientes de correlação cruzada apresentaram valores significativos apenas a partir de uma defasagem de 1,5 anos para praticamente todas as zonas de pesca. Neste estudo, confirma-se que, em águas cubanas, correlações cruzadas significativas entre estas duas variáveis ambientais medidas por satélite e as capturas da lagosta espinhosa ocorrem principalmente durante o ciclo de vida planctônico desta espécie.

Descritores*: concentração de clorofila, temperatura de superfície do mar, capturas da lagosta, correlação cruzada. ¶*

INTRODUCTION

The Caribbean spiny lobster, *Panulirus argus* is widely distributed throughout the tropical and subtropical waters of the Western Central Atlantic Ocean, ranging from North Carolina, United States, to Sao Paulo, Brazil, and extending through Bahamas, Bermudas and the Greater and Lesser Antilles. They are usually recorded at shallow waters, but they may occur on depths up to about 90 m (Tavares 2002, León et al, 2005). This lobster is one of the most economically important species in the Caribbean. About 26 countries are involved in the fishery and the commercialization. Cuba, the Bahamas and Brazil, are the largest producers with more than 60% of the total catch in the region, followed by United States, Honduras and Nicaragua (Ehrhardt, 2001).

In Cuba the spiny lobster is the most important marine resource. The fishery profits are around US$ 80 million per year and there are thousands of people on coastal communities dedicated to extractive and industrial activities related to lobster fishery (Baisre, 2000). However, the captures have been decreasing from an average of 11000 ton in the 80's to an average of 6500 ton in 2005, representing a reduction of 36%, besides the great interannual variability of captures that exists (Puga, 2005). These facts are leading the scientific community to study biotic and environmental variables that can explain the diminishing of captures, as well to contribute for future fishing operation forecasting.

The lobster is a crustacean that has both bentonic and planktonic stages during its life cycle. The adult female, which is bentonic, after mating they incubate their eggs and release them at the edge of the shelf, which mainly happens between February and May (Cruz and León 1991). The *phyllosomata* larvae are oceanic and planktonic, and concentrate on the water column between 0 and 50 m depths (Austin, 1972; Yeung and McGowan, 1991; Yeung and Lee 2002). After metamorphose into post-larvae, a stage that begins to resemble the adult, they can swim actively near the surface towards the coast (Calinsky and Lyons, 1983). This takes place every month of the year, but there is a main peak between September and December (Cruz *et al.* 1995).

When they arrive at the coast they settle in clumps of algae or any other structure suitable for hiding and mute again into juveniles (Cruz *et al.* 1995). Around July and August, usually 10 to 15 months after settlement, the juveniles go to the nursery grounds where they live hidden in caves, coral reefs and sponges, amongst others. Later on, between March and May, the juveniles enter the fishery ground. This happens approximately two and a half years after the eggs have hatched (León *et al.* 1991 and Cruz *et al.* 1991).

The lobster fishing resource forecasting and estimation must be studied by measuring the parameters that affect its distribution and abundance. For many years, environmental variables have been used to correlate the spatial and temporary distribution of marine species (Santos, 2000).

For the Batabanó Gulf, Gómez (1980) established a relation between air temperature and the peak of lobster mating females to determine breeding seasonality. Baisre and Cruz (1994) suggested that the strong winds of Hurricane Gilbert affected the marine floor of the spiny lobster nursery grounds through the southern coast of Cuba in 1988. Alfonso *et al.* (1999) outline the gradients of SST and depth as being the two main factors that influence the larval dynamic. Moreover, they indicate a limitation of the *panulirus* larval distribution on the water column related to the thermocline and the restriction of larval movement over the 26°C isotherm for Cuban waters.

Baisre *et al.* (1984), Hernández (1988), García *et al.* (1991), Hernández *et al.* (1995), Hernandez and Puga (1995), studied the massive lobster migrations that occur on the period between October and December. They related this behavior as a response to the first strong environmental perturbation such as cold fronts and tropical hurricanes. Also, Hernandez (2002) studied the influence of sea surface temperature (SST) anomalies on spawns and recruitments of the spiny lobster *Panulirus argus* at the Batabanó Gulf, all with good levels of statistical significances considering the lags between recruitment and the adult phase suitable for fishery. Somoza *et al.* (2006) analyzed the cross-correlation between SST anomalies derived from the Advanced Very High Resolution Radiometer (AVHRR) sensors and lobster captures between 1997 and 2004.

In spite of the good results obtained in scientific researches where satellite information are used to help fishing activities, there are few amount of institutions of this economic branch that recognize and/or apply this potential to develop the fishing sector (Souza, 2005). Most of the remote sensing applications that are used on fishing activities have as a primary target to increase fishery productivity. According to Santos (2000), some advantages of the uses of remote sensing techniques in the aid of fishery activities are: a) fuel economy when searching certain species; b) smaller costs with the crew; and c) reduction of maintenance costs with boats.

The ocean color measurements intrinsically include chlorophyll concentration (photosynthetic pigments of the phytoplankton), which commonly is considered as a biological productivity index for oceanic environment (Gower, 1972).

The quantification of phytoplankton productivity using ocean color sensors, such as the Sea Viewing Wide Field of View Sensor (SeaWiFS), by taking into account the chlorophyll concentration as an indicator for deep waters adjacent to the Cuban shelf can be an alternative. This biotic environmental variable would allow the exploration of possible relationships between primary productivity and lobster recruitment success at the fishing zones, since the lobster has a planktonic life of up to 12 months. However, it is necessary to take into account the 2 to 3 years of lag that exists between the hatching of the eggs and the adult recruitment for fisheries.

In this context, this work has as main objective to analyze the relations between chlorophyll concentration variability and lobster captures at the deep water adjacent to Cuban Shelf fishing zones, for a time series from 1997 to 2005. It also aims to do improve the analysis of Somoza *et al.* (2006), who compared SST data and lobster captures, by making a reanalysis with the anomalies of both variables for the same period.

MATERIAL AND METHODS

Study Area

The selection of the study area was determined by taking into account the spatial distribution of the spiny lobster life cycle over the Cuban waters. According to Cruz *et al.* (1990) and a consideration of FAO (2002) that the Caribbean lobster population could be interconnected through the water circulation regimen. Therefore, the area selected is located between 18°-25°N and 73°- 87°W.

The study area was divided in regions of interest (ROI) which are oceanic waters adjacent to the Cuban spiny lobster fishery zones (Figure. 1) described below:

- "*Jardines de la Reina*" archipelago (Zone A), situated in the southeast shelf of Cuba (18328,8 km2). This region includes 661 keys and islets, and the southeastern shelf of Cuba defined by the Gulf of "*Ana María*" and the Gulf of "*Guacanayabo*";
- "*Los Canarreos*" archipelago (Zone B), situated in the southwestern shelf of Cuba (21851,2 km2). This region includes 672 islands, keys, and islets, the biggest of which is "*Isla de la Juventud*" and the southwestern shelf of Cuba defined by the Gulf of "*Batabanó*";

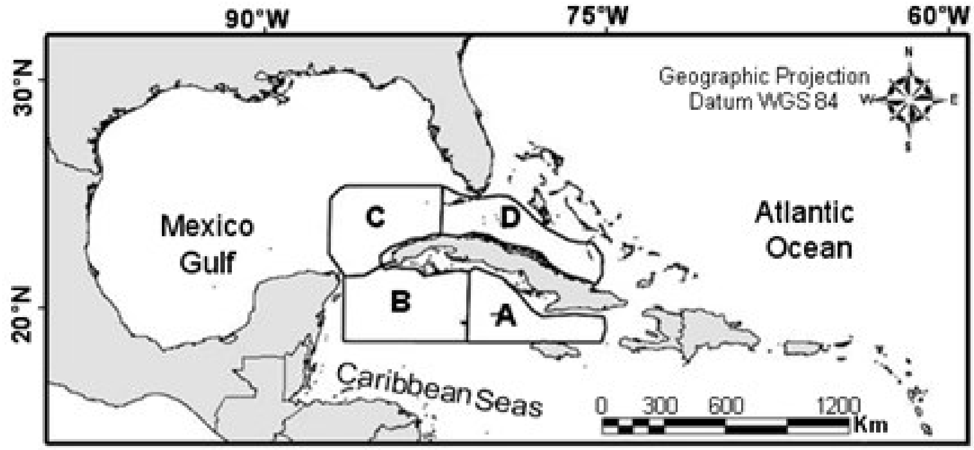

Fig. 1 Study area and regions of interest.

- "*Los Colorados*" Archipelago (Zone C), situated in the northwest shelf of Cuba (3432,5 km2); with 160 keys and islets; includes the northwestern shelf of Cuba defined by the Gulf of "*Guanahacabibes*";
- "*Sabana-Camagüey*" archipelago (Zone D), situated in the northeastern shelf of Cuba (10739,8 km2), is also known as "*Jardines del Rey*". This region consists of 2,517 islands, keys and islets; it includes the northeastern shelf of Cuba and several large bays.

At the insular shelf waters, the bathymetry is characteristic of shallow waters. They have a mean depth of about 7m at the occidental and north-oriental regions (Zones B, C, and D), and greater depths for the south oriental region, oscillating between 15 and 25m (Zone A). At zones where the coastline is not surrounded by shallow waters, depths strongly increase a few kilometers away from the coast. The bathymetry of the ROIs are typical of deep waters, oscillating between 500 to 5500m, thus being classified as Case I waters (Morel y Prieur, 1977; Morel, 1980).

Data set

The fisheries zones were obtained from the Biologic-Fisher Lobster Atlas (Cruz *et al.*, 1990). Monthly catches in metric tons for the whole period (1997-2005) were taken from statistical books from the Ministry of Fishery Industry to every fishery zone. The standardized anomalies were then calculated for each fishing zone.

The chlorophyll pigments have a specific and distinguishing spectral signature. They absorb in wavelengths corresponding to blue (455-492 nm) and red (622-700 nm) colors and they have strong reflectance in green (492 – 577 nm). On deep waters away from the coasts line, known as Case I waters (Morel y Prieur, 1977; Morel, 1980), the ocean color is mainly modified by photosynthetic organisms (Stewart, 1985). Thus, Chl-a values can be quantified by orbital ocean color sensors.

The Chl-a data were obtained from SeaWIFS images that are available on the Ocean Color web site at http://oceancolor.gsfc.nasa.gov/cgi/level3.pl. The Level 3 data are available HDF format on a global scale with cylindrical equidistance projection. They have a spatial resolution of 9x9 km and are monthly binned. There are 100 images for the period between September, 1997 and December, 2005. All images were previously corrected for atmospherically effects (Gordon and Wang, 1994).

The SST data used was the AVHRR Oceans Pathfinder Global 4 km equal-angle all SST v5 (NOAA, NASA) product for the period between 1997 and 2004, which was the same used by Somoza *et al.* (2006). In order to complete the series, monthly mean SST data of each ROI were obtained from analysis of 9x9 km spatial resolution MODIS Aqua monthly SMI (Standard Mapped Image) products from the Ocean Biology Processing Group (OBPG), available online: http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.aqua.shtml

Image processing

SeaWiFs data were processed with the routines Swl10 (version 3.0) and SeaDAS ® software, both distributed by the SeaWiFs Project (NASA), using respective standard algorithms and masks. Chlorophyll-a values were obtained using a global algorithm (O'Reilly et al. 2000). Each image was cut using the respective Region of Interests (ROI) boundaries. The monthly mean, climatology and standardized anomalies (mean=0 and standard deviation=1) values of Chl-a were calculated for each ROI using IDL scripts to the ENVI® software (ITT Visual Information Solutions).

Correlation analyzes

Taking into account that some authors (Hernández, 2002 and Somoza, 2006) studied the influence of sea surface temperature (SST) anomalies on spawns and recruitments of the spiny lobster *Panulirus argus* observing good levels of statistical significances considering 2 years of lagging between recruitment and the adult phase suitable for fishery. Also that, Ciotti and Kampel 2001, observed that there is a clear relationship between the decrease in temperature and the increase in chlorophyll-a concentration. A cross-correlation analysis was made between the standardized anomalies of the environmental variables (Chl-a and SST) and the standardized anomalies of lobster captures for each ROI. Since the correlations are not made directly between larvae data and environmental variables, but between captures of adult lobsters, the correlations were made taking into account time lags of 1.5, 2 and 3 years. Correlation analysis for the closed season month's wont be shown on the graphics and tables of this work due there are not captures allowed during this period.

RESULTS

Chl-a climatology and anomalies

Chlorophyll concentration (Chl-a) climatology images (Fig.2) of the study area showed larger concentrations and stronger variations at the Gulf of Mexico than at the Western Caribbean Seas. The concentrations were also highest around the coastal zones, especially at the mouth of the Mississippi river at the Gulf of Mexico.

A seasonal behavior is also evident along the year. In spring and summer (from April to September), the values were generally lower. At areas of water deeper than 500m the values were lower than 0,10 mg/m^3 and for shallow coastal waters the Chl-a vary between 0, 25 and 1 mg/m^3. In fall and winter (from October to March) the Chl-a had a slight increase with values exceeding 0.10 mg/m^3 at deep waters and 2 mg/m^3 at shallow waters.

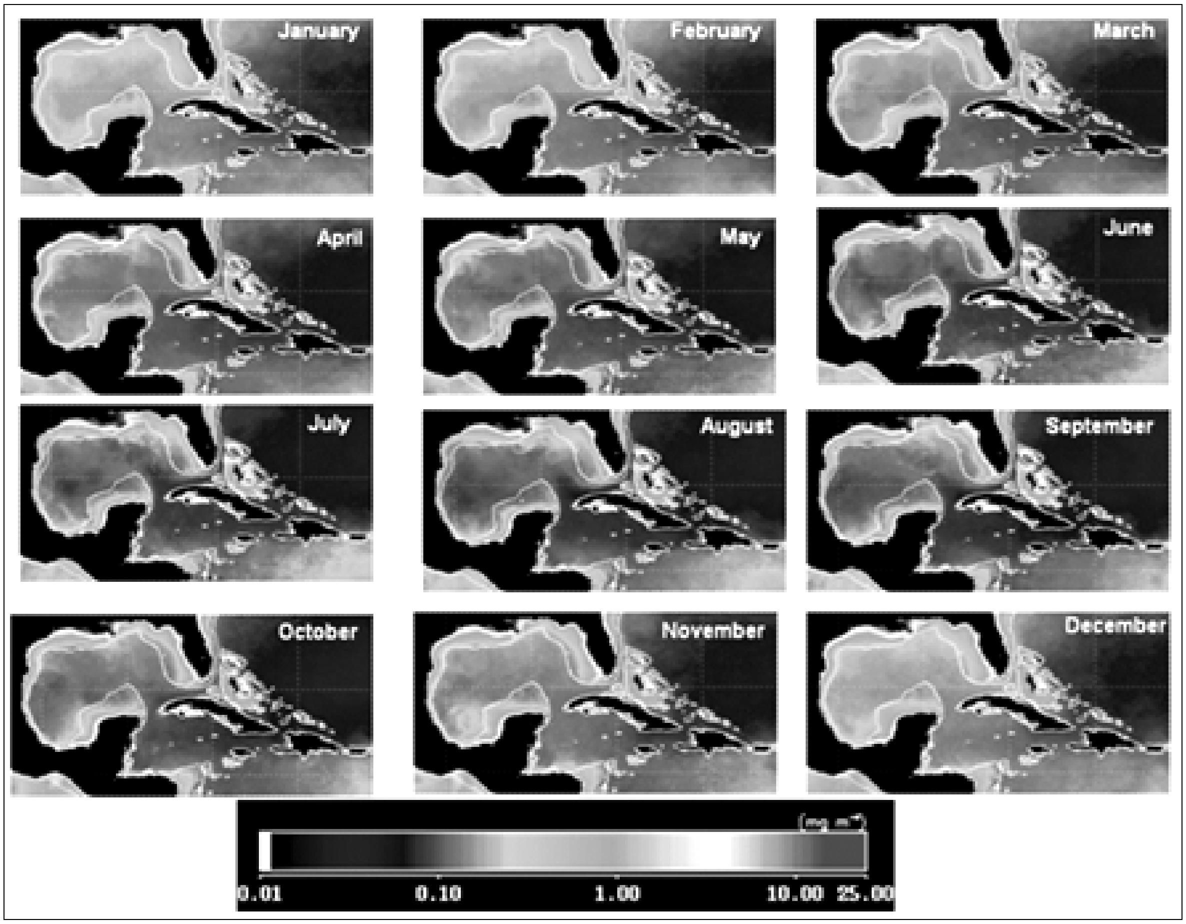

Fig. 2 Climatologic SeaWiFS images (Sep/1997-Dec/2005 period). In white a 500m depth line.

For waters adjacent to the fishing zones it was not observed a clear seasonality (Fig. 3). In general, Chl-a values are lower on the southern side of the Island. The highest values were found between December and January (0.17 mg/m^3) and the lowest in August (0.11 mg/m^3). However, the situation is different north of the Island. The Chl-a achieve maximum values between September and October (0.39 mg/m^3), and minimum on April (0.25 mg/m^3).

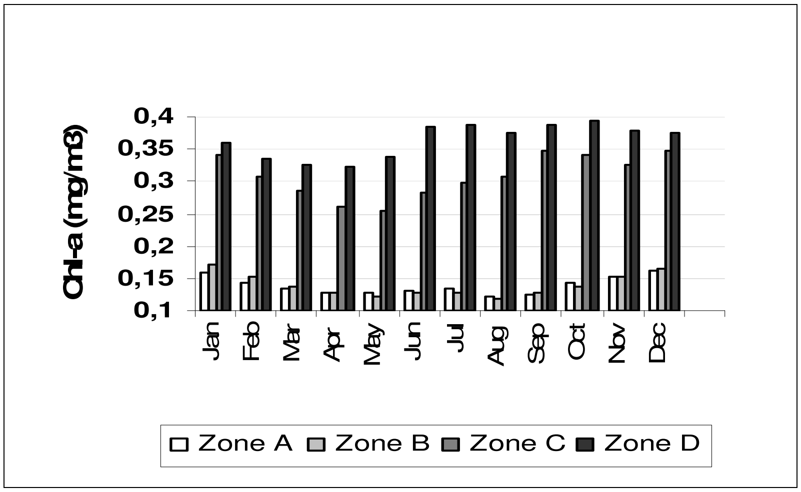

Fig. 3 Monthly climatologic mean of Chl-a for each ROI.

The Chl-a time series vary on a similar fashion for all 4 zones having high cross-correlation coefficients between them (Table 1). The zones south of the Island (A and B) present the highest correlation (0.87). While for the northern zones the correlation coefficient is lower, but significant (0.68). As it was expected due to the greater distance, the lowest correlation coefficients were found amongst zone D and the southern zones A and B (0.37 and 0.20, respectively).

Table.1 Cross-correlation coefficients for each ROI.

	Zone A	*Zone B*	*Zone C*	*Zone D*
Zone A	1			
Zone B	871	1		
Zone C	523	573	1	
Zone D	368	204	686	1

The amplitude variability of the Chl-a anomalies (Fig. 4) reach 0,11 mg/m^3 on average. The positive maximums that stand out occurred on the following periods: I) Jan-Mar/1998; II)

Nov/2001, III) Sep/2002 y IV) Jul-Nov/2005. The Zone A presented a maximum positive anomaly on Nov./2001 (0,04 mg/m^3) and a minimum on Oct./2003 (-0,02 mg/m^3). The Zone B reached a maximum on Mar/1988 (0,04 mg/m^3) and a minimum on Nov/2000 (-0,02 mg/m^3). The Zone C showed a maximum on Nov/2005 (0,11 mg/m^3) and a minimum on Oct/2000 (-0,05 mg/m^3). The Zone D achieved the maximum on Sep./2005 (0,09 mg/m^3) and a minimum on Oct/2004 (-0,06 mg/m^3). Maximum amplitudes were observed on the north at Zone C (0,16 mg/m^3). On the southern side of the Island they were similar for both zones (0,06 mg/m^3).

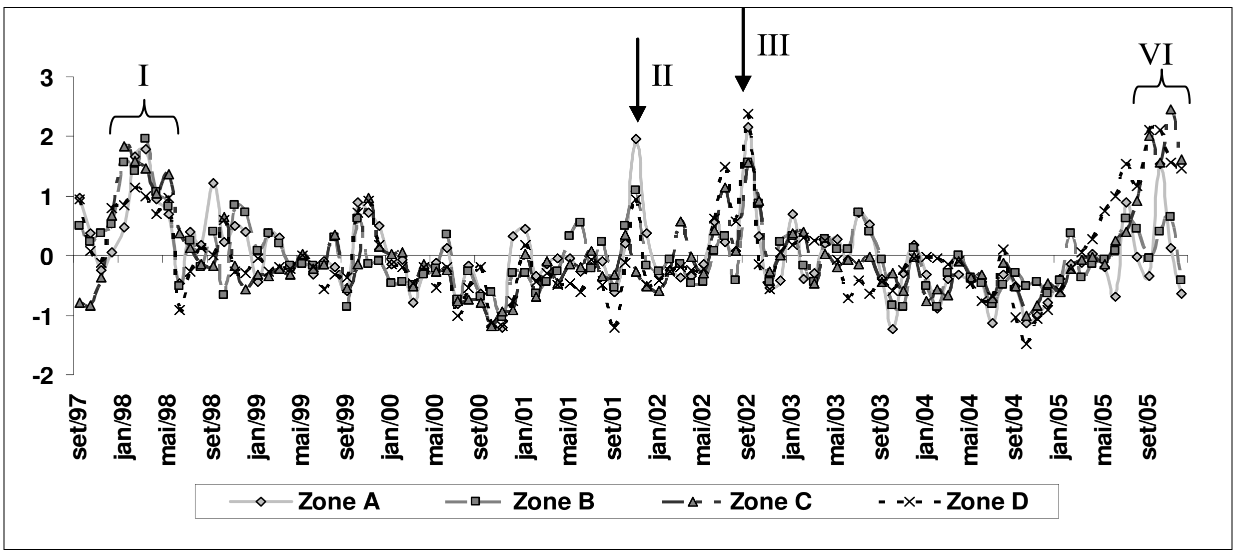

Fig. 4 Chl-a anomalies Sep/1997- Dec/2005 period (Mean=0 and Standard deviation = 1). Items I, II, III, IV are the higher positive variability for the time series.

Fisheries

Two periods per year can be described for lobster fishery: one after the closed season, with maximums in June; and another at the end of the year, called *recalo*. The second period begins when the first strong environmental perturbation such as cold fronts and tropical hurricanes appears, mainly in October, November or December, depending on the area.

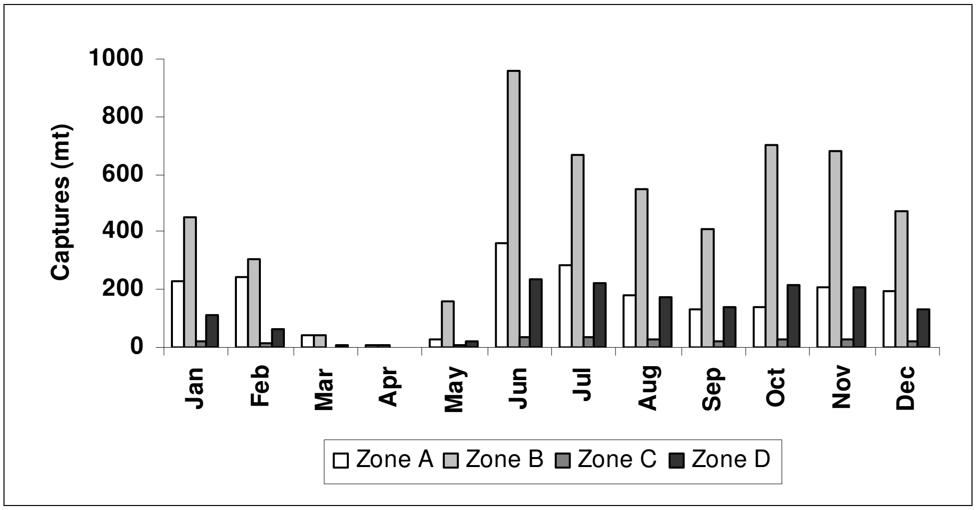

Fig. 5 Monthly mean for each fishery zone (1997- 2005 period). Note that on the closed season period (March-May), captures are not allowed.

The closed season is a protection measure that occurs from March to May, which has been extended recently to 110 days including February or June, indistinctly. The closed season protects both the spawning and the recruitment at the fishing areas, during the peak months for these processes (Arce and León 2001). In addition, there is a regulation on the minimal legal length of caught (72 mm of carapace length since 2006). The spiny lobster reaches this minimal legal length with 1,5 years of age, approximately (Cruz and León 1991).

Cross-correlation coefficients

It was made an analyze taking into account the annual anomalies mean for each variables (Fig.6). It was observed that between TSM & Captures, better correlations coefficients correspond to 1.5 years of lagging on the zone A and D (0,3 for both). Between Chl-a & captures the correlations coefficients were better for 3 years of lagging (Zone D with 0,4).

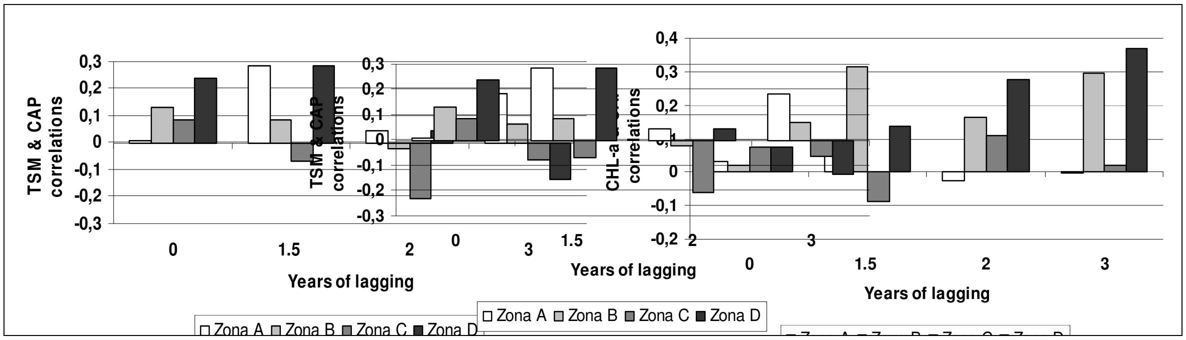

Fig. 6 Annual mean standardized anomalies cross-correlations (left side: SST & Captures; Right side: Chl-a & Captures.)

In general, cross-correlations coefficients reach highest values between Chl-a & captures for annual mean anomalies than for SST & captures. Looking for a detailed analyzes on behalf of each study zone it was made a monthly cross-correlation evaluation (Table 2).

At Zone A, it was observed for 1,5 year of lagging the best correlation with SST on July while for Chl-a was in October. For 2 years of lagging correlation coefficient with SST was low, getting the best (-0, 45) in October, but to Chl-a this coefficient reach up to -0,66 in June. With tree years of lagging significant correlation values was observed to Chl-a in February, June and October.

For Zone B, it was observed for 1,5 year of lagging the best correlation of captures with SST on September while for Chl-a was in December. For 2 years of lagging the best correlation coefficient found for SST was in December, to Chl-a coefficient also reach up this maximum in December. With tree years of lagging significant correlation values was observed to Chl-a in October and November and for SST in October.

At zone C, it was determined the best correlation with SST on December while for Chl-a was in February for 1,5 year of lagging. Taking into account, 2 years of lagging the captures best correlation coefficient with SST was in October, and with Chl-a was in

January and October. With tree years of lagging significant correlation values was observed to Chl-a in July and December and for SST in February.

Table. 2 Cross correlation coefficients (Cap & SST and Cap & Chl-a), with 1,5; 2 and 3 years of lagging)

Zone A	Jan	Feb	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	1.5 years								
Cap & SST	-0,06	0,19	-0,23	*0,66*	0,15	*0,56*	-0,15	0,17	0,43
Cap & Chl-a	-0,20	-0,32	-0,44	0,34	-0,25	0,38	*0,60*	0,06	-0,05
	2 years								
Cap & SST	0,38	-0,13	-0,05	-0,24	0,15	-0,05	-0,45	-0,01	0,41
Cap & Chl-a	-0,03	0,43	-0,66	0,13	-0,02	*0,60*	-0,31	-0,21	0,03
	3 years								
Cap & SST	0,15	-0,13	0,11	-0,11	0,22	0,23	0,04	0,12	0,26
Cap & Chl-a	0,32	*0,61*	-0,58	0,03	-0,03	-0,12	0,63	0,19	-0,09
Zone B	**Jan**	**Feb**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
	1.5 years								
Cap & SST	-0,25	-0,04	-0,15	-0,21	-0,06	0,47	-0,29	0,41	0,31
Cap & Chl-a	-0,19	-0,58	-0,08	*0,54*	0,51	-0,16	-0,03	0,30	*0,68*
	2 years								
Cap & SST	0,29	-0,12	0,13	0,21	-0,55	-0,63	-0,64	0,19	*0,67*
Cap & Chl-a	-0,18	0,40	0,47	0,13	-0,31	0,36	-0,24	-0,10	*0,66*
	3 years								
Cap & SST	0,19	-0,28	0,09	-0,16	0,10	0,05	0,40	-0,16	-0,23
Cap & Chl-a	-0,07	0,45	0,40	0,08	0,45	-0,37	*0,70*	0,85	-0,08
Zone C	**Jan**	**Feb**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
	1.5 years								
Cap & SST	-0,47	0,44	-0,28	0,09	-0,28	-0,44	-0,11	0,04	0,85
Cap & Chl-a	-0,46	-0,58	-0,17	-0,23	-0,24	-0,39	-0,39	0,02	-0,12
	2 years								
Cap & SST	-0,18	0,32	0,06	0,16	-0,31	-0,23	-0,63	-0,36	-0,18
Cap & Chl-a	-0,68	-0,31	0,15	0,04	-0,80	0,19	-0,67	*0,57*	0,42
	3 years								
Cap & SST	-0,36	-0,50	-0,42	-0,09	-0,33	-0,11	-0,10	0,03	0,00
Cap & Chl-a	-0,45	0,24	-0,59	-0,71	0,35	0,11	-0,16	0,38	0,71
Zone D	**Jan**	**Feb**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
	1.5 years								
Cap & SST	-0,24	-0,14	*0,64*	*0,59*	0,28	0,49	-0,55	0,21	-0,02
Cap & Chl-a	0,05	-0,01	-0,41	0,16	-0,20	0,37	0,41	-0,12	0,28
	2 years								
Cap & SST	0,03	0,04	-0,42	0,17	-0,01	-0,05	-0,51	0,18	*0,54*
Cap & Chl-a	0,11	0,28	0,01	-0,38	0,27	0,81	0,49	-0,18	*0,51*
	3 years								
Cap & SST	0,35	-0,23	-0,02	-0,83	0,45	0,14	-0,64	-0,55	-0,56
Cap & Chl-a	0,64	0,57	-0,17	0,62	-0,01	0,70	0,37	0,64	0,30

For zone D, it was calculated the best correlation between captures and SST on June while for Chl-a was in June and October for 1,5 year of lagging. Regarding to 2 years of lagging the captures best correlation coefficient with SST was in December, and with Chl-a was in December too. With tree years of lagging significant correlation values was observed to Chl-a in September and for SST in July.

DISCUSSION AND CONCLUSION

Pérez *et al.*, 1990, explain that the increase of Chla-a on winter months at the study area is due to the weakening of the thermal stability during this time of the year, and to an improvement on the nutrient regime (Fernández y Chirino,1993). The clear tendency of decrease in the pigment density during summer points out to the importance of the role of thermal stability as being a determinant of the surface chlorophyll content (Victoria *et al.*, 1990).

In situ samples made at the study site between 1978 and 1986 by Melo et al 1995, showed that during winter an intense vertical mixing is produced due to the decrease of the sea surface temperature and due to the increase of the intensity and persistence of winds and waves. This yields a thickening of the mixing layer up to around 110m (Table 3) and favors the input of nutrients from deep waters into the euphotic zone, which yields higher levels of primary production (Fernández y Chirino 1993).

Table. 3 Seasonal behaviors of the main physical-chemical characteristics of the ocean waters around Cuba, according to Victoria *et al.* 1990.

	Solar radiation [MJm^{-2} day^{-1}]	Thickness of the Mixing Layer [m]	Mean Sea Surface Temperatura [°C]	Mean NO_2+ NO_3 concentration [μ $molL^{-1}$] (0-200m)	Mean PO_4 concentration [μ $molL^{-1}$] (0-200m)
Winter	14,2	100-125	26,0	1,06	0,14
Summer	19,3	30-50	29,7	0,95	0,05

Moreover, during winter, incident solar radiation decreases (National Atlas of Cuba, 1989). According to Koblentz-Mishke *et al.* (1977), the chlorophyll content inside the cells increases with the decrease of incident solar radiation and with the increase of the concentrations of biogeochemical elements on the environment; both processes characterize the winter period.

During summer, the increase of solar radiation and the decrease of the wind regime yield a thickening of the sea surface layer with strong thermal stratification, limiting the vertical mixing and consequently the entrance of nutrients into the euphotic zone (Corredor, 1977). The thickness of the surface mixing layer is around 40m (Table 6), and solar radiation reaches the highest values. At this season, despite the higher levels of phytoplankton concentration and biomass as reported by Perez *et al.* (1990), the chlorophyll levels sensibly decrease as result of the decrease of nutrients on the mean and due to the increase of the incident solar radiation.

The positive peaks encountered on the series were mostly associated to extreme meteorological events. On the first period, between Jan-Mar/1998 the positive anomaly (Fig.4) was especially high south of the island. García et al (1998) described the winter season between 1997 and 1998 as being very active, since 26 cold fronts reached Cuba due to the presence of ENSO. The authors also point out that a new record was established for the winter season, being the month of February the most significant due to the southern winds. Also Piñeiro (2004) express that 100% of front colds that affect the island inside on the zone C. Regarding to the cases II, III, and IV (Fig. 4), where the maximum values achieved were 0,04 mg/m^3, 0,08 mg/m^3 and 0,10 mg/m^3, respectively, the positive anomalies were associated to a behavior described by Babin *et al.* (2004), as a response to the injection of nutrients and biogenic pigments on oligotrophic waters with the cooling of waters after the passage of hurricanes (Table 4). Walker (2005) describe that satellite-derived SST, SSH, and Chl-a measurements clearly revealed rapid upwelling responses along and east of Ivan's hurricane path where pre-existing cyclonic circulation experienced intensification. Venting of thermoclines and nutriclines can explain the SST cooling response of 3–7°C and subsequent Chl-a enhancement.

Table. 4 Hurricanes that pass through the Caribbean waters and inside on monthly Chl-a anomalies. (UNISYS, 2007)

Name	Data	Max wind (mph)	Min Pres (mb)	Category Saffir-Simpson Scale	Study area impact
Hurricane EMILY	11-21/JUL/2005	140	929	5	South
Hurricane KATRINA	23-31/ AUG/2005	150	902	5	North
Hurricane RITA	18-26 /SEP/2005	155	897	5	North
Hurricane ISIDORE	14-27/ SEP/2002	110	934	3	South/ North
Hurricane LILI	21SEP-04OCT/2002	125	940	4	South/ North
Hurricane MICHELLE	29 OCT-06 NOV/ 2001	120	934	4	South/ North

The increase of Chl-a in June and July agrees with enrichment of the Caribbean waters by the North Brazil Current, which transports waters from the Amazon Plume and reaches the highest Chl-a values at this time of the year (0.5 to 5 mg/m^3), as described by Pérez *et al.* (2004).

Fisheries

Cruz *et al.* (1990) established that the maximum captures occurs after closed season due to the fisheries regimes with the country's fishery management, they remain practically null during a period of 110 days in order to protect animal breeding, growth and the incorporation of recruitments to the fishery. While the second peak registered maximum on the *recalo* period according to Baisre (1994) is due to the displacement of surface waters of the shelf, by the action of continuous intense winds from east during severe cold fronts, which can cause the entrance of deeper and colder water of the slope, trigging massive lobster migrations towards the coast during winter.

Figure 5 shows that the highest mean captures are obtained on the Zone B situated southeast of the island and covering. This zone has the greatest fishing area (21,851.2 km^2), and many authors point this as being the zone of greatest productivity due to the high availability of food, refuges, as well as the environmental qualities (Cruz *et al.*, 1990; 1995; Baisre and Cruz, 1994; Baisre *et al.*, 1984; Baisre, 2000, amongst others). The lowest captures occur on the Zone C, which is situated on Northwest of the island and covers the smallest fishing area (3,438.5 km2). Baisre and Cruz (1994) state that the distribution of captures are related to the extension of the fishing zones, the mean depths, the fishing gears used, and the habitat and food availability.

Cross-correlation coefficients.

Taking into account the annual anomalies mean for each variables it was observed that cross-correlations coefficients reach highest values between Chl-a & captures than for SST & captures. Mainly it was determined positive correlations for both variables, although there were some punctual negative significant correlation coefficient values to SST for 2 years of lagging in Zone C. Acording to Polovina *et al.* (2001), these oceanographic variables (SST and Chl-a) are of critical importance in the early life history because of their hypothesized relationships to larval growth and feeding success, both critical determinants of larval survival and successful recruitment. It was shown on figure 6, through the cross-correlation coefficient between Chl-a and captures, how the food availability on the larvae stages might influence on the lobster captures.

The Chl-a on marine waters have been used as and indicator of phytoplankton abundance. Since lobster larvae feed on phytoplankton or other plankton organisms that feed on phytoplankton, it is known that there is a synchronism between the periods of abundance of food and the peaks of larvae abundance in marine population. This is a strategy of larval survival that is tuned with natural selection (Baisre, 1984). Therefore, it is reasonable to find major correlations between the abundance of phytoplankton and lobster larvae. Cruz *et al.* (1990) state that, following the trophic chain, these planktonic populations that feed the lobster larvae have greater abundance on ecosystems that yield better life condition, namely where there is more food available. No doubt these sites can be found where there are greater Chl-a, which is commonly used as a biological productivity index and in an ocean environment, it can be related to species abundance. For example, Chl-a higher than 0.2 mg m-3 indicate a presence of sufficient planktonic life to sustain a viable commercial fishing (Gower, 1972).

In a monthly cross-correlation analyze was found that there are two significant periods for SST & captures coefficient, a positive correlation for western zones (B and C) in the winter months December and January for 1,5 years of lagging, while for the eastern zones this positive correlations occurs in the summer months June and July also for 1,5 years of lagging. Looking for negative correlations between SST & captures was originated a significant coefficient in October of 2 years of lagging for all study zones.

Regarding to Chl-a & captures cross-correlation coefficient each study zone had its own behavior. The maximum positive coefficients values were reached for all zones with 3 years of lagging, being the maximum values for zone B on November. While maximum negatives were obtained to the zones B and D for 1.5 years of lagging and to zone A and C for 2 years of lagging. Puga (2005) estimates that the mean ages of captured animals by fishing zones vary between 2.5 and 7 years, and they depend on the depth of the zone, being that the youngest catches occur on zone D and the oldest occur on Zone A.

Sea surface temperature and chlorophyll-a concentration are widely available from a variety of satellite sensors, and both of these variables may have important linkages to the ecology of early life history stages, for growth and mortality (Polovina *et al.* 2001). Larval food supply involves spatial and temporal patchiness, and the species composition of the phytoplankton and microzooplankton is critically important (Lasker, 1975). In addition to starvation issues, variability in food supply has been shown to be an important determinant of larval growth and subsequent survival (Booth and Alquezar, 2002).

The correlation coefficients obtained leads to the reasoning that the studied environmental variables in the lobster life cycle would be more related to the larval phase that is developed on oceanic waters. On this work it is corroborated that significant correlation between these two environmental variables (SST and Chl-a) measured by satellite with spiny lobster captures are mainly for planktonic life cycle of this specie on the Cuban waters.

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