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The response of shrimp fisheries to climate variability off Baja California, México

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The effect of climate variability on the shrimp fishery in the upper Gulf of California and the west coast of southern Baja California was investigated using artisanal and industrial catches of blue shrimp (*Litopenaeus stylirostris*) and brown shrimp (*Farfantepenaeus californiensis*). Catch data were compared with the Southern Oscillation Index (SOI) and remotely sensed environmental parameters, including sea surface temperature, chlorophyll *a*, coloured dissolved organic matter, and particulate organic carbon (Rrs412 and Rrs490). Overall, temperature was the best environmental indicator of commercial shrimp catches. Catches of blue shrimp varied directly and of brown shrimp indirectly with the SOI in their dominant areas, suggesting that the two species are influenced by *El Niño* conditions in different ways.

Keywords: AVHRR, Baja California, blue and brown shrimp, climate variability, *El Niño*, SeaWiFS.

Introduction

The abundance of species with short life cycles, such as anchovy (family Engraulidae), sardine (family Clupeidae), and shrimp, are often influenced by environmental factors, increasing their vulnerability when fishing and environmental effects coincide. Changes in environmental conditions can affect recruitment success, resulting in variable year-class strength that affects the fishery directly (Aragón-Noriega, 2007). Consequently, environmental variability should be an important consideration in management strategies for such species. The purpose of this study was to determine the association between environmental parameters and shrimp catches off San Felipe (SF) in the upper Gulf of California and off the west coast of southern Baja California (WCSBC).

The Mexican shrimp fishery has been important commercially since the 1950s; the catch in 2004 was 58 000 t, worth US$24 m (FAO, 2006a, b), with the Gulf of California producing the largest portion of the catch (SAGARPA, 2009). The main species caught are blue (*Litopenaeus stylirostris*), brown (*Farfantepenaeus californiensis*), white (*L. vannamei*), and crystal shrimp (*F. brevirostris*). There are two fishing sectors, artisanal and industrial (SAGARPA, 2009). The artisanal fishery is conducted by unions, cooperatives, or independent fishers using small (6–9 m long, 55–100 hp) boats and trawls in shallow coastal waters. The industrial fishery is typically conducted with larger (18–25 m, 240–624 hp) boats in both shallow and deeper water by large fishing companies (Gillett, 2008). Note that the term industrial is used here to identify the non-artisanal fishery and that it should not be confused with so-called "industrial" fishmeal fisheries.

The upper Gulf of California is an area with high levels of primary productivity, which is reflected in higher trophic levels (Millán-Núñez *et al.*, 1999). Environmental variability has previously been studied in the area using satellite data (Santamaría-del-Ángel *et al.*, 1994a, b; Flores-de-Santiago *et al.*, 2007; López-Calderón *et al.*, 2008), but there have been no studies of primary productivity for the WCSBC, and only a few physical studies examining vertical mixing and its effect on nutrient transport and primary productivity (Durazo, 2009) have been done. In addition, there have been no *in situ* biological studies of shrimp in the area. Nevertheless, considering the low trophic level of shrimp and the likely strong influence of environmental factors on their growth (Glantz, 1992), reproduction, and recruitment, an investigation of the relationship between shrimp catches and relevant remotely sensed environmental factors could result in a predictive capability that could be useful in fishery management.

Material and methods

Annual catches of blue and brown shrimp off SF and in the WCSBC were obtained from annual reports of the Mexican Secretary of Fisheries (Secretaria de Pesca, 1986, 1987, 1988, 1989) and the Secretary of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA, 2002, 2003, 2004a, b, c, d, 2005, 2006a, b, 2007, 2008, 2009). The study area and locations of the SF and the WCSBC shrimp fishery areas are shown in Figure 1.

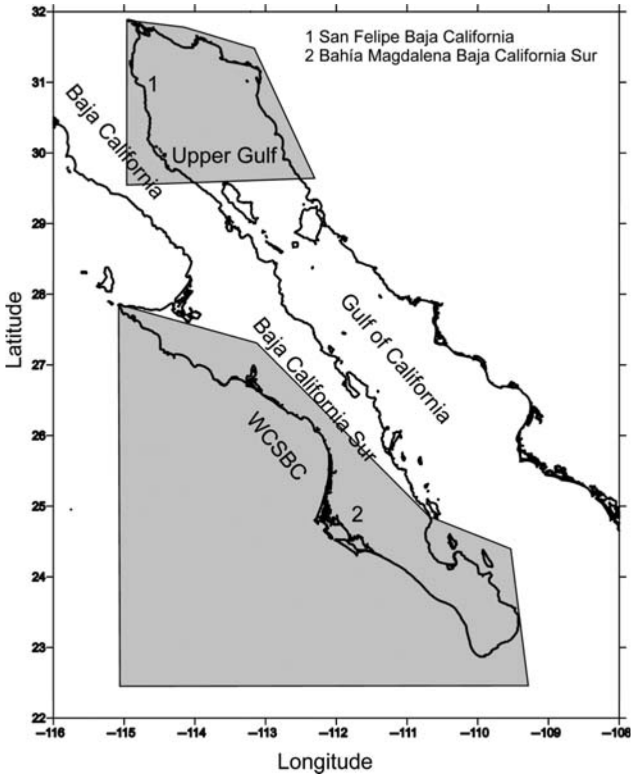

Figure 1. Gulf of California, with fishing areas of the upper Gulf of Baja California and the west coast of southern California (WCSBC) highlighted in grey.

Table 1. Principal component analyses for SF Baja California and the WCSBC, with for each area the results of the eigenanalysis and the Pearson's correlation coefficients.

SF parameter	**PC1**	**PC2**	**PC3**
Eigenvalue	4.147	2.163	1.269
Proportion of the total variability explained by each PC	0.461	0.240	0.141
Cumulative total variability explained by cumulative PC	0.461	0.701	0.842
Parameter	**Comp. 1**	**Comp. 2**	**Comp. 3**
Total	0.168	**0.904**	−0.102
Industrial	−0.567	0.185	**−0.766**
Artisanal	0.399	**0.800**	0.220
SST	−0.057	**0.595**	0.251
CDOM	**0.649**	0.071	−0.681
Chl *a*	**0.900**	−0.290	0.003
POC	**0.797**	−0.398	0.291
Rrs412	**−0.973**	0.172	0.062
Rrs490	**−0.903**	−0.195	0.089
WCSBC parameter	**PC1**	**PC2**	
Eigenvalue	6.244	1.409	
Proportion of the total variability explained by each PC	0.694	0.157	
Cumulative total variability explained by cumulative PC	0.694	0.850	
Parameter	**Comp. 1**	**Comp. 2**	
Total	**−0.800**	−0.610	
Industrial	**−0.654**	0.117	
Artisanal	**−0.714**	−0.700	
SST	**−0.721**	−0.483	
CDOM	**0.942**	0.095	
Chl *a*	**0.852**	−0.408	
POC	**0.924**	−0.216	
Rrs412	**−0.940**	0.157	
Rrs490	**−0.887**	0.264	

The most significant correlation coefficients are shown emboldened (alpha 5% is 0.514 for SF Baja California and 0.602 for the WCSBC).

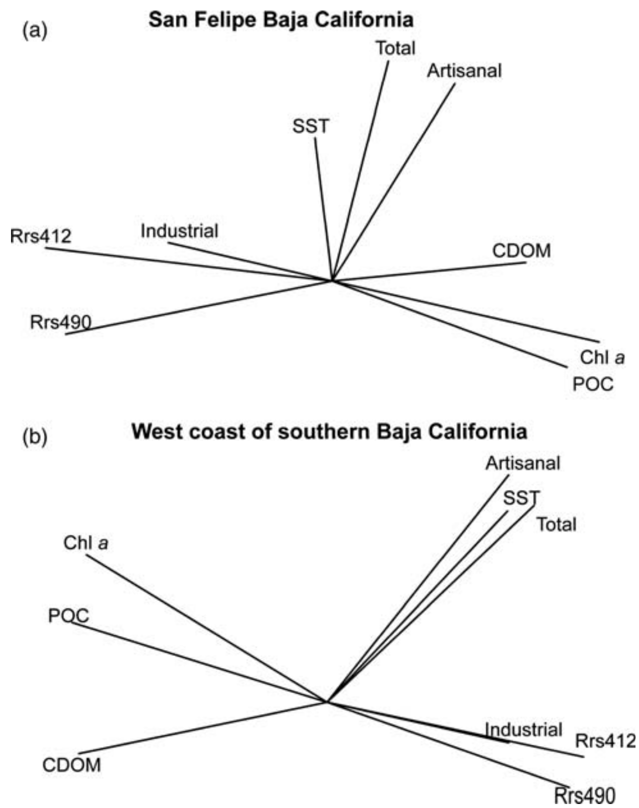

Figure 2. Vector graphics from factor analysis between shrimp catches and environmental indices from remote-sensing data in (a) SF Baja California; and (b) the WCSBC.

Owing to differences in the level of reporting over time and resulting analytical limitations, catch data were aggregated for analysis as follows: (i) species combined; (ii) separated by area and fishing sector, i.e. total catch (1985–2008); (iii) industrial and artisanal catches (1994–2008); and (iv) fishing sectors combined, separated by species, 1985–2001 for SF, and 1986–2008 for WCSBC.

Remotely sensed indicators of the environment included sea surface temperature (SST) derived from Advanced Very High Resolution Radiometer (AVHRR) data, using the Pathfinder algorithm version 5, and chlorophyll *a* (Chl *a*) concentration, coloured dissolved organic matter (CDOM), particulate organic carbon (POC), and remote-sensing reflectance at 412 nm (Rrs412) and 490 nm (Rrs490) obtained from SeaWiFS (Sea-viewing Wide Field-of-view Sensor), using the standard algorithms (O'Reilly *et al.*, 2000; Patt *et al.*, 2003; Stramska and Stramski, 2005; Mannino *et al.*, 2008; Djavidnia *et al.*, 2010). Annual geometric

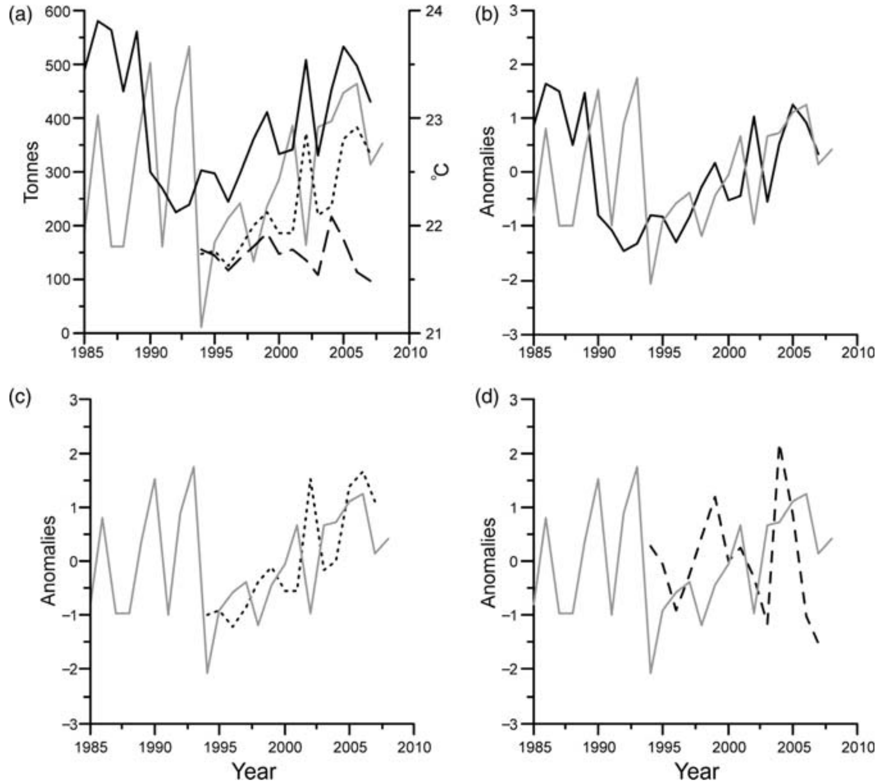

Figure 3. SF Baja California: (a) SST (grey), total catch (black), artisanal catch (dotted), and industrial catch (dashed); (b) SST (grey) and total catch anomalies (black); (c) SST (grey) and artisanal catch anomalies (dotted); and (d) SST (grey) and industrial catch anomalies (dashed).

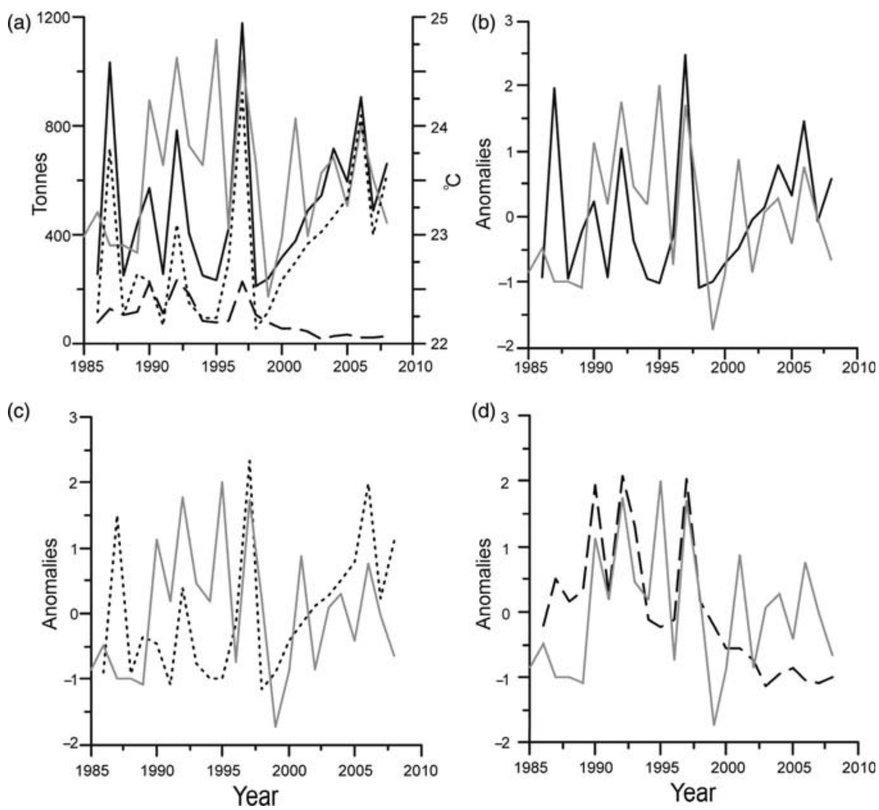

Figure 4. WCSBC : (a) SST (grey), total (black), artisanal (dotted), and industrial catch (dashed); (b) SST (grey) and total catch anomalies (black); (c) SST (grey) and artisanal catch anomalies (dotted); and (d) SST (grey) and industrial catch anomalies (dashed).

averages were calculated for each region (Figure 1) for images with a pixel size of 9 × 9 km. Anomalies were calculated and standardized using the *Z*-transformation (datapoint minus the average, divided by the standard deviation).

Principal component and factor analyses were conducted to determine relationships between catches and environmental indicators. Cross-correlation analysis was used to examine possible time-lags between catches and SST. Finally, a trend analysis was conducted based on the slope (*b*1) of a simple linear regression model using catch and SST as dependent variables, and years as the independent variable (1994–2007 for SF, 1994–2008 for WCSBC).

Table 2. Trend analysis for SF Baja California and the WCSBC based on the slope (*b*1) of a simple linear regression model using catches and SST as dependent variables and years as the independent variable.

Parameter	SF		WCSBC	
g.l.	12		13	
t_{crit}	2.178		2.160	
Year	1994–2007		1994–2008	
Alpha 5%	*b*1	t_{cal}	*b*1	t_{cal}
Total	**17**	**4.32**	24.1	1.55
Industrial	−0.094	−0.043	**−7.84**	**−3.13**
Artisanal	**17.9**	**5.27**	**30.8**	**2.21**
SST	**0.126**	**4.65**	−0.034	−0.90

Emboldened numbers indicate significant slopes (i.e. greater than t_{crit}).

Annual averages of the Southern Oscillation Index (SOI) were calculated using monthly data available at http://www.bom.gov.au/climate/current/soi2.shtml.

Results

For SF, the principal component analysis (Table 1) displayed three components (eigenvalues >1) that explained 84.2% of the cumulative total variability of the catch (all species). The total catch and the artisanal catch were directly related to SST (PC2), whereas the industrial catch was not associated with any variable (PC3). There were two principal components for WCSBC (Table 1), explaining 85% of the total variability. All variables were associated with the first component (the highest correlation coefficients were obtained for this component). Total, artisanal, and industrial catches were all directly related to SST, Rrs412, and Rrs490, and inversely related to CDOM, Chl *a*, and POC (Table 1, Figure 2b). Factor analysis confirmed these results (Figure 2), particularly the relationship between total and artisanal catches and SST in both areas. As observed off SF, the total catch in the WCSBC was mostly made up of artisanal catches (Table 1, Figure 2b).

Time-series plots (Figures 3 and 4) also reflected the direct relationship between SST and shrimp catches in both areas. Trend analysis (Table 2) indicated a significant increasing trend in artisanal catches since the mid-1990s in both areas. However, SSTs increased significantly only off SF and displayed no trend in the WCSBC. Industrial catches in the WCSBC declined

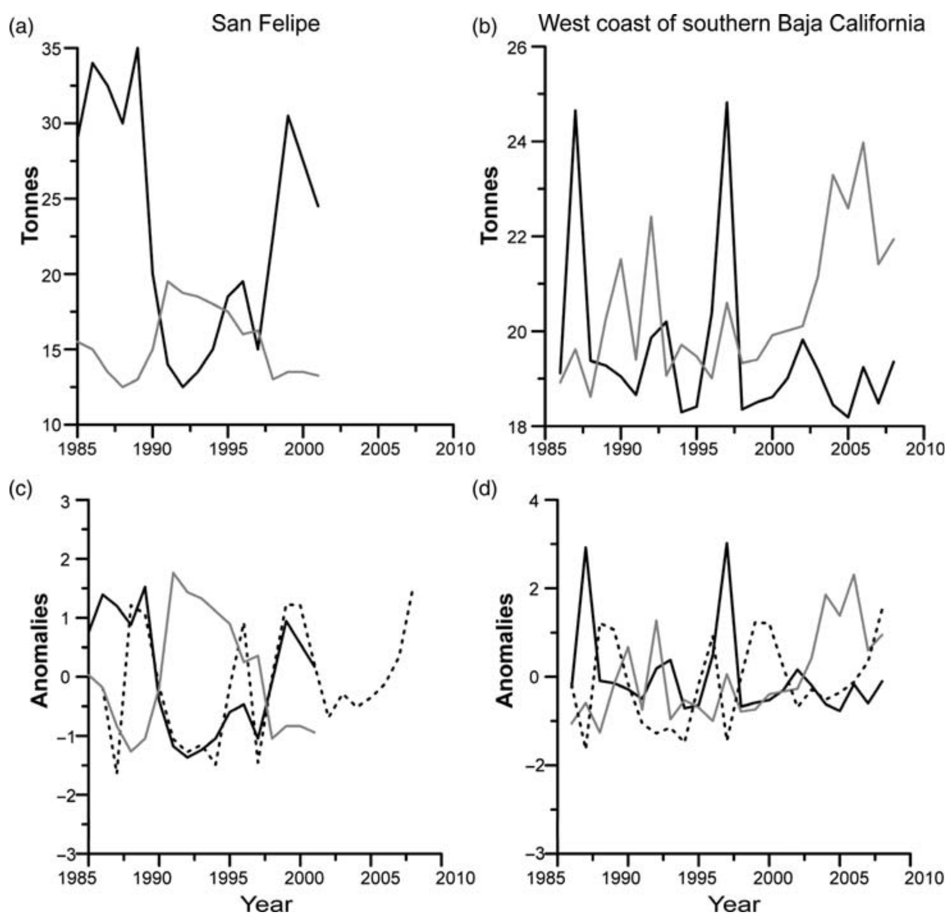

Figure 5. Blue (black line) and brown shrimp (grey line) catches for (a) SF Baja California, (b) WCSBC. Anomalies for annual SOI (dotted line) and blue (black line) and brown (grey line) shrimp catches for (c) SF Baja California, and (d) WCSBC.

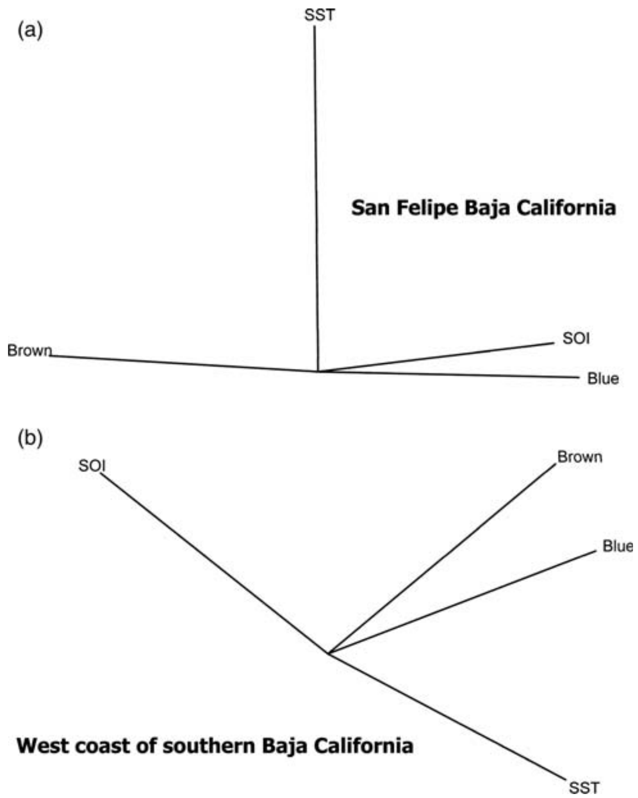

Figure 6. Vector graphics from factor analysis for (a) SF Baja California, and (b) WCSBC.

notably from the mid-1990s. The maximum positive linear correlation between SST and catch was with a 1-year time-lag (total catch, $r = 0.737$; artisanal catch, $r = 0.766$) off SF. The artisanal catch dominated the total catch in both areas (Figures 3a and 4a). Note also that temperatures in the WCSBC averaged ~2°C higher than off SF.

For species, time-series plots indicate that blue shrimp tended to dominate catches off SF, whereas brown shrimp dominated in the WCSBC (Figure 5a and b). Off SF, catches of the two species appeared to be inversely related to each other (Figure 5a, $r = -0.834$), whereas there was no clear pattern for the WCSBC. Blue shrimp appeared to vary positively and brown shrimp negatively with the annual SOI (Figure 5c), but this pattern was also less clear in the WCSBC. Factor analysis (Figure 6a) for SF data confirmed that the association with the SOI was positive for blue and negative for brown shrimp and that catches of the two species were negatively correlated. The same analysis for the WCSBC (Figure 6b) shows the negative relationship between SST and the SOI.

Two *El Niño* events during the study period (1992/1993 and 2002/2003) exhibited the typical negative SOI and positive SST anomalies (Figure 7).

Discussion

The analysis was complicated by changes in the level of catch reporting over time and the unavailability of effort data for calculating catch per unit effort. The latter precludes any conclusions being drawn pertaining to environmentally caused changes in abundance. In addition, management measures changed during

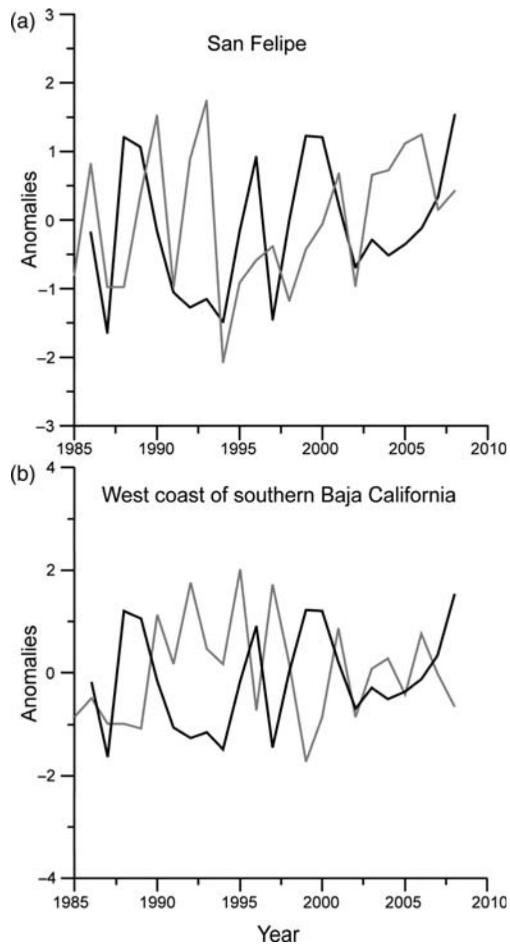

Figure 7. SOI (black) and SST anomalies (grey) for (a) SF Baja California, and (b) WCSBC.

the study period. In particular, the establishment of the Biosphere Reserve of the Upper Gulf of California and Colorado River Delta, which excluded most industrial fishing from the upper Gulf after 1993 (García-Juárez *et al.*, 2009), contributed to the dominance of artisanal catches off SF.

Despite those data limitations, the results suggest strong environmental influences on shrimp catches in both study areas, perhaps reflecting changes in shrimp abundance and hence their availability to the fishery. There was a strong association between catches and SST. Most relationships were without time-lags, but one suggested that warmer years yielded better catches the following year. Because of the lack of *in situ* biological information, the mechanisms underlying this relationship are obscure, although Aragón-Noriega (2007) suggests that warmer temperatures allow reproduction over a longer period. Our results are similar to those of Li and Clarke (2005) for brown shrimp in the Gulf of Mexico and by González-Yañez and Ortiz-Bultó (2002) for pink shrimp in Cuba.

In this study, the catches of brown and blue shrimp off SF exhibited opposite patterns relative to the SOI, suggesting that *El Niño* conditions favour brown shrimp and non-*El Niño* conditions favour blue shrimp. However, the relationships are complex and influenced by other factors. For example, Galindo-Bect (2003) reported opposing results for blue shrimp catches off SF relative to *El Niño*. The upper Gulf is influenced by discharge from the

Colorado River, whose delta has high nutrient concentrations (Hernández-Ayón *et al.*, 1993), turbidity (Santamaría-del-Ángel *et al.*, 1996), and primary productivity (Millán-Núñez *et al.*, 1999). Increases in discharge should increase nutrients and productivity, including that of the shrimp population (Galindo-Bect *et al.*, 2000).

There were no significant relationships between shrimp catch and remotely sensed spectroradiometric products (Chl *a*, POC, CDOM, Rrs412, Rrs490). One would expect a functional relationship between Chl *a* and survival of planktonic larvae, but this might not necessarily have been reflected in commercial catches during the relatively short period when satellite data were available. A longer time-series will likely be required to explore further the patterns observed and to develop predictive population models that include environmental parameters.

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