IMPACTS OF INTERANNUAL ENVIRONMENTAL VARIATION ON THE SHRIMP FISHERY OFF THE GULF OF CALIFORNIA

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ABSTRACT

This work presents an exploratory analysis of the potential relationship between offshore shrimp catches and environmental factors at the Gulf of California, using shrimp harvest information from Guaymas, Sonora, and Mazatlán, Sinaloa, México. Multiple correlation analysis was used to examine the relationships between landings time series and environmental variables, including average rainfall, fluvial discharge, the Pacific Decadal Oscillation (PDO) and the El Niño Multivariate (MEI) Indices. Environmental index series were split for January through June (cold season) and July through December (warm season), since shrimp populations show two reproduction peaks throughout the year. These two spawning seasons give rise to two cohorts: the cold-season (April–June) and the warm-season (October–November), the former sustaining the fishery during the open season (September–March) and yielding 90% of total catch between September and October. Our findings indicate that the mean PDO index for the cold season accounted for the highest percentage of catch variation, suggesting that conditions during the cold season (January–June) may determine recruiting in the April–June cohort. This information may be used to derive catch forecasts several months in advance.

INTRODUCTION

The offshore shrimp fishery in the Gulf of California produces over 70% of the total shrimp harvested along the Mexican Pacific coast (Sierra et al. 2000); Guaymas, Sonora and Mazatlán, Sinaloa, are the two major fishing ports (fig. 1). The fishery consists of an artisanal fleet which is made up of small pangas (outboard powered boats) in inshore lagoons and the adjacent coasts at less

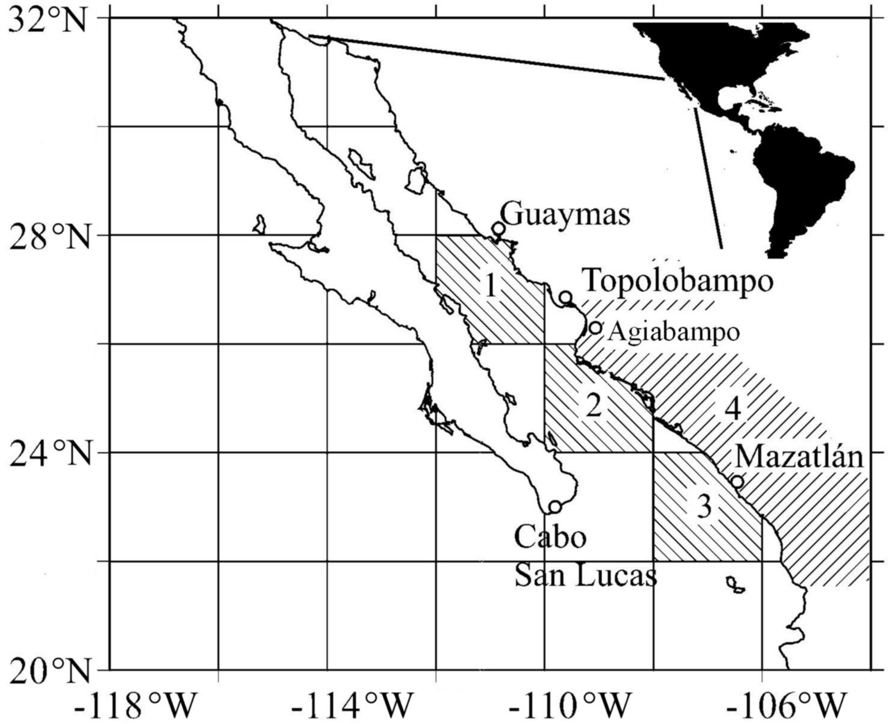


Figure 1. Location of quadrats for which sea surface temperatures (SST) were obtained (1, 2, and 3), and of the coastal meteorological stations and dams from which rainfall and incoming river flow data (4) were gathered.

than 5 fathoms deep, and an industrial fleet made up of shrimp trawlers fishing in offshore waters. The artisanal fleet is estimated at ca. 20,000, whereas the industrial fleet has more than 900 trawlers for Guaymas and Mazatlán (SEMARNAP, 2005). The industrial fleet has been operating since the 1970s under adverse economic conditions derived from overcapitalization (Meltzer and Chang 2006). This has resulted in low annual per-vessel catch yields, declining from some 24 tons during the 1960s to less than 10 tons, on average, over the past 15 years. The fishing season for the offshore fishery usually starts in mid-September and, although it may last six months, is more intense during the first two months when nearly 90% of total catch is harvested. These low yields make the industrial fleet particularly susceptible to natural fluctuations in shrimp abundance, with years of profits alternating with years of losses, so that a forecast tool allowing shrimp fishing operations to plan ahead of the fishing season would be useful.

It has long been suggested that the variability of penaeid shrimp abundance is related to the physical environment (Castro-Aguirre 1976; Vance et al. 1985; Catchpole and Auliciems 1999; Galindo-Bect et al. 2000; Lopez-Martinez et al. 2002; Lee 2004; Henderson et al. 2006). These fluctuations are identified through the variability of environmental factors such as temperature, rainfall, and fluvial discharge, which in turn are related to large-scale changes associated with atmospheric and oceanic circulation dynamics. Similar analyses have been conducted by Catchpole and Auliciems (1999), who found a positive correlation between the Southern Oscillation Index (SOI) and shrimp catch in northern Australia, which was related to rainfall seasonality. Norton and Mason (2005) analyzed the variability of fish and shellfish catches on the California coast along with information on environmental factors, and identified two variability patterns at a climatic scale that were related to the tropical and northern Pacific Ocean, and detected changes in catch composition and volume.

The resilience of shrimp populations derives from their short life cycle, which results in two shrimp cohorts per year. Brown shrimp (*Farfantepenaeus californiensis*) have been found to have two periods of major reproductive activity (Romero-Sedano et al. 2004), the first during June and July and the second between October and November. These may fluctuate according to seasonal variations in temperature (Leal-Gaxiola et al. 2001). Blue shrimp (*Litopenaeus stylirostris*) have also been found to have two reproduction peaks, the first from April to June, giving rise to the spring cohort, and the second from October to January, producing the fall cohort (López-Martínez et al. 2002). The timing of cohorts suggests that it is the spring cohort that supports the fishery which starts in September. White shrimp (*Litopenaeus vannamei*) have been documented to spawn along a prolonged period, May to September, but more intensely during the first and the last months (Sepúlveda 1991). Other aspects of shrimp biology and fisheries on the Pacific coast of México have been described by Magallón (1987), Sepúlveda (1981, 1991, and 1999), and others.

In this study we examine the feasibility of using local and large-scale environmental indices as forecasting tools for relative shrimp abundance. Since landings (and hence relative abundance) have been suggested to depend largely on recruitment during the cold part of the year prior to the fishing season, it is assumed that the environmental factors occurring during April through June may have a key influence on the next fishing season.

MATERIAL AND METHODS

Two sets of shrimp landings data from Guaymas, Sonora and Mazatlán, Sinaloa from Sierra et al. (2000) were analyzed. Guaymas data include catch time series for blue shrimp between 1985 and 1999, and both catch and CPUE (catch per unit of effort) for brown shrimp between 1975 and 1999; Mazatlán data include catch time series for blue, brown, and white shrimp between 1983 and 1999. Landings are from the offshore fishing season ranging from September to March of the following year, commonly beginning the second half of September. Also included are landings from the artisanal fishery (caught during August to February), except for those of brown shrimp at Guaymas (which are only from the industrial fleet) including CPUE information. Data are shown in Table 1.

Environmental information corresponds to two different geographic scales: regional data, including rainfall (P) and fluvial discharge (F); and large-scale indices, such as the Pacific Decadal Oscillation index (PDO), which accounts for the variability in the northern Pacific Ocean, and the El Niño Multivariate Index (MEI), which represents the variability in the tropical Pacific Ocean. Additionally, sea surface temperature (SST) and rainfall data were used to derive mean climate estimates of the seasonal variation. Table 2 includes a brief description of the type of information used and the respective source. SST data were obtained from the U.S. National Climatic Data Center (NCDC) database, whereas rainfall and fluvial discharge data were obtained from Brito-Castillo (2003) for coastal basins in Sonora and Sinaloa, as shown in Figure 1. Time series of environmental variables were averaged for two periods, one corresponding to the cold season, January to June, and the other corresponding to the warm season, July to December.

A first analysis, aimed at identifying the best indices for the purpose of forecasting, was performed by means of multiple linear correlations using each of the landings series (C) as the independent variables, seasonal averages

TABLE 1
Shrimp catch (metric tons) landed at Guaymas, Sonora, and Mazatlán, Sinaloa, México.

	Mazatlán Catch (tons)			Guaymas Catch (tons)		CPUE (t/trip)
Season	Blue	White	Brown	Blue	Brown	Brown
1975–76					1713.8	0.591
1976–77					3550	1.046
1977–78					2970	0.716
1978–79					3140	1.233
1979–80					2210	1.008
1980–81					2910	1.168
1981–82					2400	1.018
1982–83					1280	0.517
1983–84	4470	3360	2110		2150	1.120
1984–85	4270	2930	2100		1450	0.867
1985–86	5240	2760	1650	2950	2210	1.140
1986–87	4160	1450	1940	3400	2910	1.457
1987–88	6380	1840	2360	2920	2000	1.014
1988–89	4410	1030	2230	1610	1920	1.095
1989–90	4640	1400	2360	1560	2090	1.470
1990–91	3330	760	1430	1320	1400	0.798
1991–92	2110	1530	2550	1250	1570	0.783
1992–93	4040	1310	1860	1060	2150	0.821
1993–94	3620	1980	2800	1790	2440	1.025
1994–95	4240	1860	2490	2110	2800	1.292
1995–96	4240	1310	2380	2540	3140	1.414
1996–97	5700	1100	1630	2070	2560	1.152
1997–98	5700	2780	2200	2790	3550	1.880
1998–99	3870	1140	2060	1460	1600	0.736
1999–2000	6000	900	2340	2150	2400	

TABLE 2
Summary of climatic variation indices and sources.

MEI - Multivariate El Niño index, Wolter and Timlin 1998. Obtained from EOF analysis of central Pacific SST monthly anomalies. http://www.cdc.noaa.gov/people/klaus.wolter/MEI/table.html (Access date; June 2005)
PDO - Pacific Oscillation Decadal index, Mantua et al. 1997. Obtained through EOF analysis of North Pacific SST monthly anomalies. http://jisao.washington.edu/pdo/PDO.latest (Access date; May 2005)
P - Regional monthly rainfall obtained from climatologic stations from Sonora and Sinaloa. Digitalized data from figures in Brito-Castillo 2003.
F - Regional monthly inflow volumes at dams (millions m^3) from Sonora and Sinaloa. Digitalized data from figures in Brito-Castillo 2003.
SST - Monthly average sea surface temperature data from Extended Reconstructed Sea Surface Temperature (ERSST), 2° x 2° quadrants centered at 23°N–107°W; 25°N–109°W and 27°N–111°W. http://lwf.ncdc.noaa.gov/oa/climate/research/sst/sst.html (Access date, January 2006)
Climatological monthly data of rainfall from http://www.inegi.gob.mx/est/contenidos/espanol/rutinas/ept.asp?t=mamb98&c=5843 (Access date, January 2006)

for the cold season (subscript c), and seasonal averages for the warm season (subscript w):

$$C = b_0 + b_1 PDO_c + b_2 PDO_w + b_3 MEI_c + b_4 MEI_w + b_5 P_c + b_6 P_w + b_7 F_c + b_8 F_w.$$

Later, the two variables with the largest effect on observed variability were identified as those variables with the highest absolute value of the weighted beta coefficient because this indicated the relative weight of the variable as a predictor.

Then, series were filtered to eliminate high-frequency variability and to facilitate the visualization of the major longer-term variation modes. For data filtering, we used Hamming 5-year windows (StatSoft 1999). Landings series were cross correlated with climatic variables, both raw and filtered, considering the seasonal averages corresponding to the warm (July–December) and cold (January–June) seasons separately. Results are shown in Table 3.

In a second analysis, multiple-linear correlation was again conducted using each of the smoothed landings series as dependent variables and the two smoothed identified environmental series as independent variables. The

TABLE 3
Correlation matrix between catch time series and climatic variables for northeastern México, upper portion = original series; lower portion (*italics*) = filtered series. The abbreviations refer to series to catch of Mazatlán (M) and Guaymas (G), and blue shrimp, *Litopenaeus stylirostris* (a); white shrimp, *L. vannamei* (b); brown shrimp, *Farfantepenaeus californiensis* (c), and catch for trip (cv). The other abbreviations refer to climate series, Pacific Decadal Oscillation (PDO) and Multivariate El Niño Index (MEI), finally pluvial precipitation (P) and fluvial discharge (F), in the warm (w) and cold (c) periods. Numbers in bold indicate significant correlation ($p < 0.05$).

	Ma	Mb	Mc	Ga	Gc	Gcv	PDOc	PDOw	MEIc	MEIw	Pc	Pw	Fc	Fw
Ma		0.4	–0.2	**0.6**	0.4	0.5	**0.6**	0.4	–0.2	0.2	0.0	–0.1	–0.2	–0.4
Mb	*0.4*		0.2	**0.6**	0.5	0.5	0.2	0.5	–0.2	**0.6**	0.0	–0.5	0.0	–0.4
Mc	*–0.3*	*–0.2*		0.0	0.2	0.2	0.0	0.3	0.2	0.3	–0.4	–0.2	–0.3	0.0
Ga	***0.8***	***0.8***	*–0.4*		**0.6**	**0.6**	**0.5**	0.4	–0.3	0.3	–0.3	–0.2	–0.3	–0.2
Gc	***0.6***	*0.4*	*0.2*	*0.5*		**0.9**	0.4	0.4	–0.2	0.4	–0.2	–0.4	–0.2	–0.4
Gcv	***0.9***	*0.3*	*–0.1*	***0.6***	***0.8***		0.2	0.3	–0.5	0.3	–0.3	–0.1	–0.4	–0.3
PDOc	***0.8***	***0.6***	*0.1*	***0.8***	***0.7***	***0.7***		0.4	0.3	0.1	0.0	–0.3	–0.2	–0.4
PDOw	*0.3*	*0.5*	*0.0*	*0.5*	*0.2*	*–0.1*	***0.6***		0.2	**0.6**	0.2	0.0	0.1	–0.1
MEIc	*–0.3*	*–0.1*	***0.6***	*–0.4*	*0.0*	*–0.4*	*0.0*	*0.3*		0.2	0.4	–0.3	0.3	–0.3
MEIw	*–0.2*	*0.3*	*0.2*	*0.0*	*0.3*	*–0.2*	*0.2*	***0.5***	***0.7***		0.1	–0.1	0.0	–0.2
Pc	***–0.7***	*0.0*	*0.0*	*–0.4*	***–0.5***	***–0.9***	*–0.5*	*0.3*	*0.5*	*0.4*		–0.2	**0.9**	–0.3
Pw	*–0.3*	***–0.7***	*–0.4*	*–0.4*	***–0.7***	*–0.4*	***–0.6***	*–0.2*	*–0.4*	*–0.4*	*0.0*		–0.3	**0.7**
Fc	***–0.8***	*0.1*	*0.1*	*–0.4*	*–0.4*	***–0.8***	*–0.5*	*0.3*	*0.5*	*0.4*	***1.0***	*0.0*		–0.2
Fw	*–0.4*	*–0.3*	*–0.2*	*–0.2*	***–0.8***	***–0.7***	*–0.5*	*0.1*	*–0.3*	*–0.3*	*0.4*	***0.8***	*0.3*	

TABLE 4

Results of the multiple correlation analysis of shrimp catch data at Guaymas, Sonora. Significant results at 5% confidence are shown in bold numbers. In the first column are variable abbreviations. The statistical abbreviations such as β coefficients represent the relative contribution of each independent variable in the prediction; the *t* value and resulting *p* value are used to test the hypothesis; R^2 is the coefficient of multiple determination. Numbers in bold indicate significant correlation ($p < 0.05$).

Guaymas, Sonora

(a) Blue shrimp (*Litopenaeus stylirostris*)

	β	B	$t_{(11)}$	p
b_0		1467.2	7.4	0.000
PDO$_c$	**0.789**	**893.1**	**4.1**	**0.002**
F$_c$	–0.068	–44.9	–0.4	0.731

$R^2 = 0.678$; $F_{(2,11)} = 11.6$; $p < 0.002$

(b) White shrimp (*L. vannamei*)

	β	B	$t_{(21)}$	p
b_0		2445.6	23.5	0.000
MEI$_c$	–0.094	–81.0	–0.5	0.653
P$_c$	**–0.538**	**-448.5**	**–2.6**	**0.017**

$R^2 = 0.353$; $F_{(2,21)} = 5.7$; $p < 0.010$

(c) Brown shrimp (*Farfantepenaeus californiensis*) (CPUE Data)

	β	B	$t_{(21)}$	p
b_0		0.989	27.208	0.000
PDO$_c$	**0.554**	**0.172**	**3.980**	**0.001**
P$_c$	**–0.507**	**–0.172**	**–3.643**	**0.002**

$R^2 = 0.595$; $F_{(2,21)} = 15.4$; $p < 0.000$

TABLE 5

Results of the multiple correlation analysis of shrimp catch data at Mazatlán, Sinaloa. Significant results at 5% confidence are shown in bold numbers. In the first column are the variable abbreviations. The statistical abbreviations such as β coefficients represent the relative contribution of each independent variable in the prediction; the *t* value and resulting *p* value are used to test the hypothesis; R^2 is the coefficient of multiple determination. Numbers in bold indicate significant correlation ($p < 0.05$).

Mazatlán, Sinaloa

(a) Blue shrimp (*Litopenaeus stylirostris*)

	β	B	$t_{(13)}$	p
b_0		3859.4	25.832	0.000
PDO$_c$	**0.670**	**887.1**	**5.586**	**0.000**
P$_c$	**–0.443**	**–483.6**	**–3.692**	**0.003**

$R^2 = 0.832$; $F_{(2,13)} = 32.2$; $p < .00001$

(b) White shrimp (*L. vannamei*)

	β	B	$t_{(13)}$	p
b_0		1043.9	5.7	0.000
PDO$_c$	**0.744**	**831.4**	**4.3**	**0.001**
P$_c$	**0.615**	**566.3**	**3.5**	**0.004**

$R^2 = 0.642$; $F_{(2,13)} = 11.7$; $p < 0.001$

(c) Brown shrimp (*Farfantepenaeus californiensis*)

	β	B	$t_{(13)}$	p
b_0		1977.4	31.4	0.000
MEIc	**0.779**	**310.9**	**3.2**	**0.007**
P$_c$	–0.476	–130.1	–1.9	0.073

$R^2 = 0.442$; $F_{(2,13)} = 5.1$; $p < 0.023$

resulting correlations, using only the two variables displaying the highest weight, are shown in Tables 4 and 5. Using only those two variables, we estimated forecasted landings which were then compared to actual data.

RESULTS

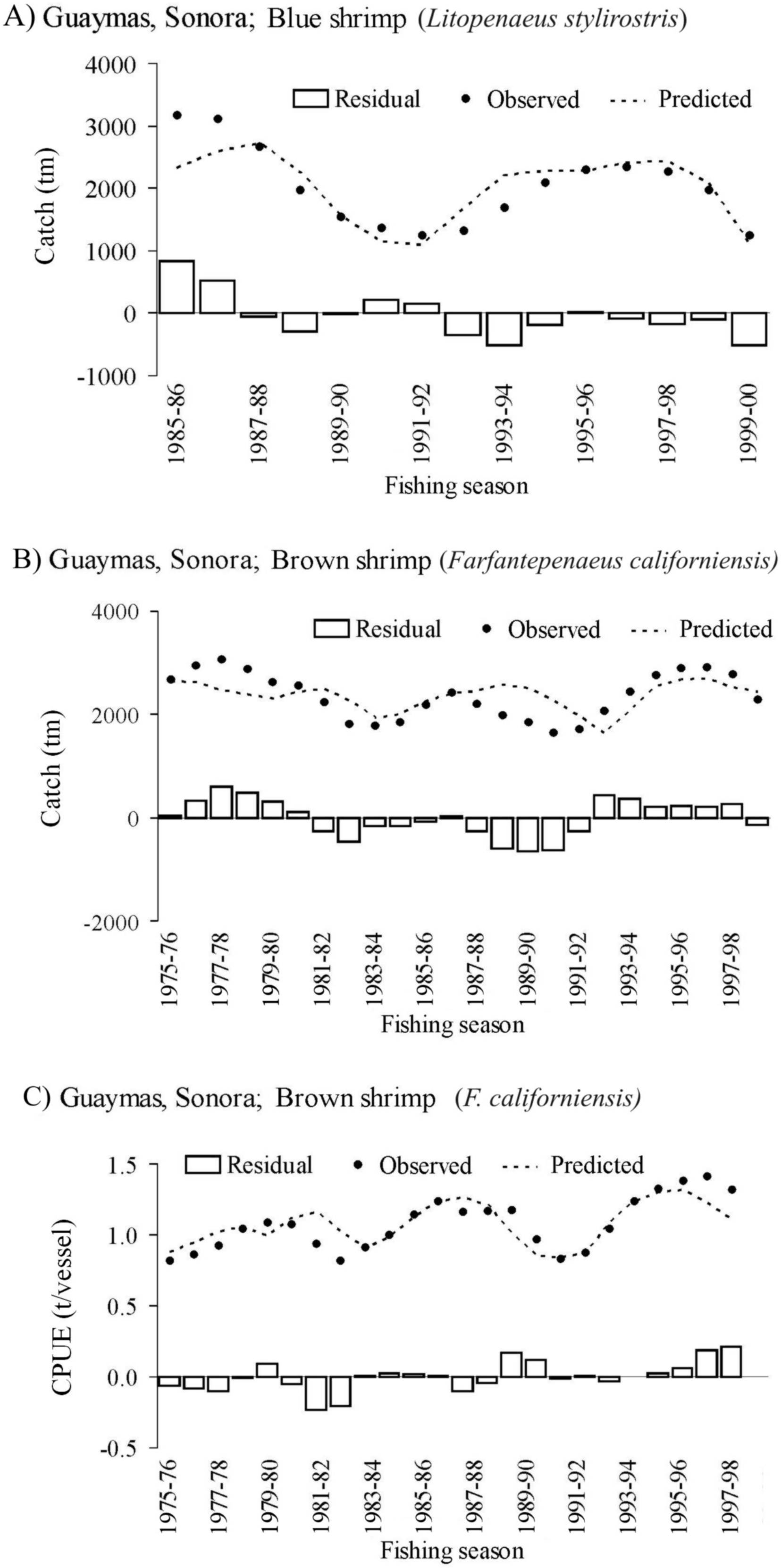
Table 3 shows the results from the cross-correlation analysis between catch time series and environmental variables summarized in two correlation matrices. The upper and lower matrices show the correlation between original and filtered (*italics*) data, respectively. The lower matrix, which shows a higher proportion of significant results, indicates that most catch series are significantly correlated with the cold season (January–June) PDO (PDO$_c$), P$_c$, MEI$_c$ and F$_c$; PDO$_c$ was positively correlated with shrimp catch; whereas rainfall was negatively correlated, except for white shrimp landed at Mazatlán which had a significant negative correlation with rainfall and river flow (P and F).

The results of multiple correlation analysis between catch and the two best fit variables are shown in Tables 4 (for Guaymas) and 5 (for Mazatlán); the name of each variable and values of the equation and weighed beta coefficients, as well as *t* and *p* values for the test of hypothesis, are shown; b_0 is not.

The comparison between forecasted and actual catch values for Guaymas is displayed in Figure 2. In the case of blue shrimp (fig. 2A), a declining trend is evident between 1988 and 1991, with the lowest values during 1991–1992. This trend may be related to the cold period mentioned by Lavín et al. (2003); from 1991 landings rise steadily to peak in 1996–1997, thereafter dropping towards the end of the period. In the case of blue shrimp, PDO$_c$ and F$_c$ account for ca. 70% of total variability ($R^2 = 0.678$), with PDO$_c$ contributing the most (β = 0.789).

Catch and CPUE data for brown shrimp at Guaymas were analyzed in two stages: first, when landings data were related to rainfall during the cold season (P$_c$; β = 0.538); and second, when landings data were related to MEI for the cold season (β = 0.094). Both account for only 35% of variability (fig. 2B). In a second stage, CPUE data were analyzed revealing that the cold-season variables PDO$_c$ and P$_c$ had similar weight as did the predictors (0.554 and –0.507, respectively), and altogether account for 59% of variability (fig. 2C).

In the three cases above, the variables had an influence on landings during the cold season. It is also evident that flow and rainfall during the cold season negatively correlate to landings and CPUE. Figure 2A-C shows the relationship between observed and calculated data; residuals show the differences between both series, highlighting the low catches after the El Niño event of 1982–1983 and the La Niña in 1989–1991.

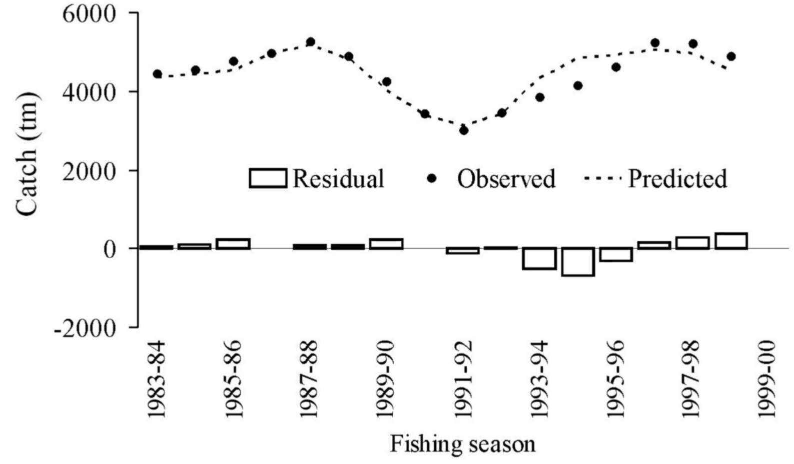

A) Guaymas, Sonora; Blue shrimp (*Litopenaeus stylirostris*)

B) Guaymas, Sonora; Brown shrimp (*Farfantepenaeus californiensis)*

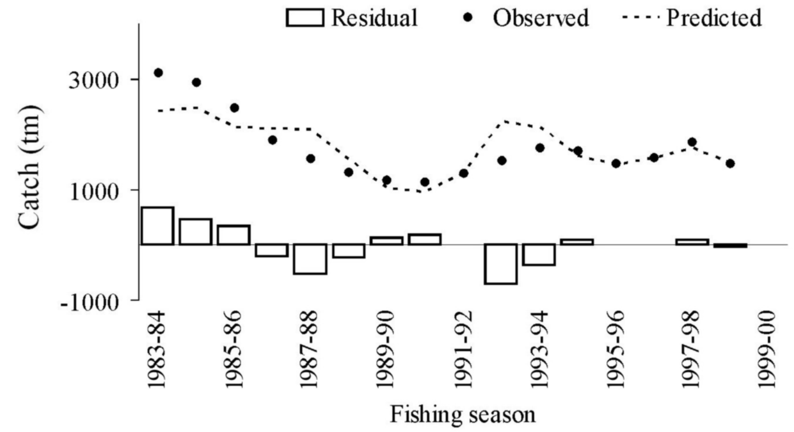
C) Guaymas, Sonora; Brown shrimp (*F. californiensis)*

Figure 2. Observed and calculated shrimp catch in metric tons from Guaymas, Sonora, for the fishing seasons 1975–76 through 1999–2000; (A) blue shrimp (*Litopenaeus stylirostris*); (B) brown shrimp (*Farfantepenaeus californiensis*); and (C) catch per unit of effort (CPUE) of brown shrimp.

A) Mazatlán, Sinaloa; Blue shrimp (*Litopenaeus stylirostris*)



B) Mazatlán, Sinaloa; White shrimp (*Litopenaeus vannamei*)



C) Mazatlán, Sinaloa; Brown shrimp (*Farfantepenaeus californiensis*)

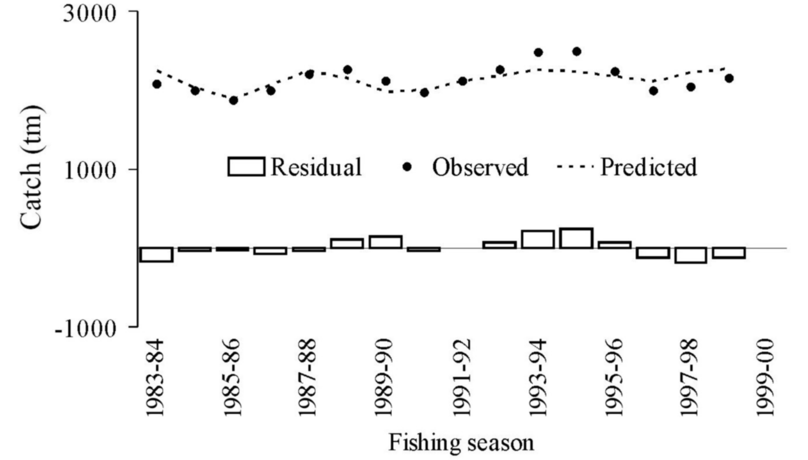


Figure 3. Observed and calculated shrimp catch in metric tons from Mazatlán, Sinaloa, for the fishing seasons 1983–84 through 1999–2000; (A) blue shrimp (*Litopenaeus stylirostris*); (B) white shrimp (*L. vannamei*); and (C) brown shrimp (*Farfantepenaeus californiensis*).

TABLE 6
Reproduction periods of the major shrimp species harvested in the Gulf of California and the source documents.

Blue shrimp (*Litopenaeus stylirostris*)		
Agiabampo	May–July	(Aragón-Noriega 2005)
Guaymas	July–August	(Sepúlveda-Medina 1991)
Mazatlán	June–July	(Sepúlveda-Medina 1991)
Brown shrimp (*Farfantepenaeus californiensis*)		
Guaymas	March–May October–November	(Leal-Gaxiola et al. 2001)
Guaymas-Mazatlán	May–September	(Sepúlveda-Medina 1991)
Agiabampo	June–July October–November	(Romero-Sedano et al. 2004)
Agiabampo	May–August	(Valenzuela-Quiñonez et al. 2006)
White shrimp (*L. vannamei*)		
Mazatlán	May–September	(Sepúlveda-Medina 1991)
Guaymas	June–August	(Sepúlveda-Medina 1991)

Results of the Mazatlán data analyses are shown in Figure 3. Again, the main variable associated with landings is PDO for the cold season ($\beta = 0.670$), followed by rainfall for the cold season (P_c; $\beta = -0.443$). Together, they account for 83% of the variability, similar to the findings for the same species at Guaymas. Results for white shrimp (fig. 3B) indicate that the two variables with the highest likelihood to be related to harvest also correspond to the cold season and are PDO_c and rainfall (P_c). However, these variables have a similar weight (0.744 and 0.615, respectively); the difference in most cases is that harvest is positively correlated with rainfall. The results for brown shrimp (tab. 5 and fig. 3C) are similar to those obtained for the same species at Guaymas, highlighting MEI_c and P_c as the two most important variables ($\beta = 0.779$ and -0.476, respectively).

DISCUSSION AND CONCLUSIONS

Our results indicate that environmental conditions for the first semester of the year (roughly corresponding to the cold season) may influence shrimp production in the Gulf of California during the following fishing season. The reproduction period which results in the recruitment which sustains the fishery was found to occur during the first semester; these findings agree with those from other investigations which are summarized in Table 6.

In most cases, the main reproduction period seems to take place during the first half of the year, and seems to depend on temperature (Aragón-Noriega and Alcántara-Razo 2005). When they compared the data from ripe females between northern and southern sites in the study area, these authors found that a well-defined peak of reproductive activity is evident at the north, where the mean SST is 22.6°C, whereas at the south, where mean SST is 26.2°C, the reproductive activity takes place throughout the year.

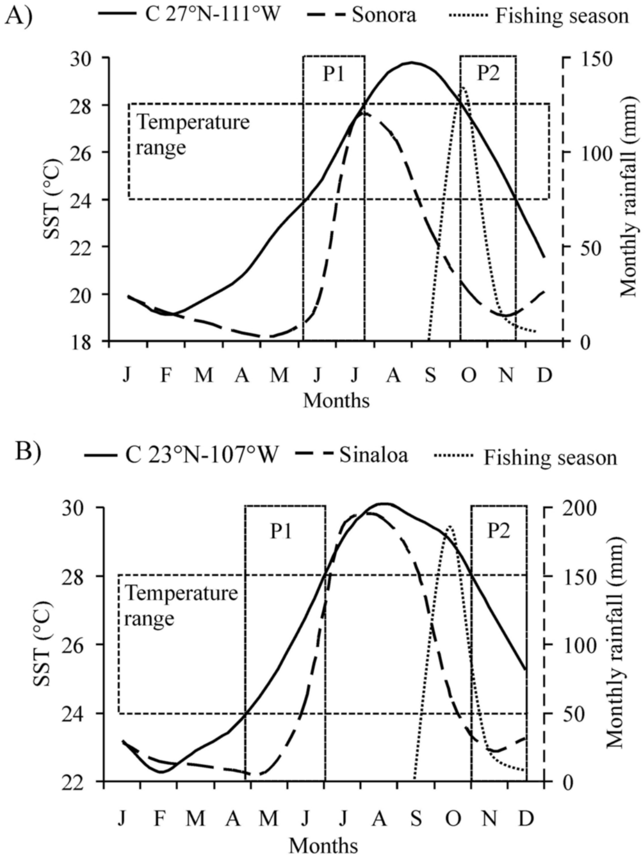


Figure 4. Seasonal SST cycles in two quadrats located at 25°and 27°N, and rainfall cycles in the Sinaloa (upper line) and Sonora (bottom line) coastal basins. The two reproduction periods reported for the three major shrimp species (blue shrimp, *Litopenaeus stylirostris*; white shrimp, *L. vannamei*; and brown shrimp, *Farfantepenaeus californiensis*) are depicted, along with catches during the fishing season.

A conceptual model of the seasonal processes in the shrimp life cycle which includes seasonal variation in SST and rainfall, reproduction periods, and fishing season, is shown in Figures 4A (Sonora) and 4B (Sinaloa).

It is worth noting that the fishing season is relatively long, between September and March of the following year, but most of the harvest is caught during the first two to three months. However, the fishing areas of the two fleets (Guaymas and Mazatlán) during the first part of the fishing season are considered to be very similar because vessels generally congregate in areas of higher shrimp density and scatter steadily towards other areas as the fishing season progresses. A key aspect in the analysis is temperature tolerance by the three shrimp species, which seemingly ranges between 24° and 28°C (Sierra et al. 2000).

Figures 4A and 4B illustrate that the first reproduction peak may be related to the ascending portion of SST, from late April in the Mazatlán area and from June farther north; a second peak of reproductive activity could occur between October and December, when SST is declining. Theoretically, the optimum SST for reproduction would be ~26°C.

If the above are true, most shrimp harvested by the Guaymas and Sonora fleets are likely from the first reproduction period, which in the case of brown shrimp gives rise to the so-called spring cohort (López-Martínez et al. 2002); the second reproduction period during the last months of the year apparently gives rise to a second cohort (fall cohort), which is important because it represents the reproductive population for the following year.

The above might explain the relationship between shrimp catch and PDO during January–June, since the influence of the north Pacific Ocean weather becomes evident as SST decreases as a result of cold weather and strong winter winds (Bernal et al. 2001). During an anomalous cold period, the reproductive activity declines as ripening processes get slower and the reproduction season becomes shorter, which results in low recruitment (Leal-Gaxiola et al. 2001; Aragón-Noriega and Alcántara-Razo 2005).

Strong warm events like those in 1982–1983 and 1997–1998 also seem to exert a negative effect on shrimp catches, probably because growth and recruitment are affected when temperature exceeds the upper limit of shrimp's thermal tolerance (López-Martínez et al. 2002).

Our findings indicate that winter rainfall (P_c) is a another factor to consider and has a negative correlation with shrimp harvest; however, winter rainfall is generally scarce, so that its influence may be relatively modest. There is the possibility that this is an indirect correlation, derived from a certain degree of correlation between PDO_c and P_c (see Table 3).

We conclude that the influence of weather during the cold season, between January and June, accounts for a significant proportion of blue shrimp catches in Guaymas and Mazatlán, which, in terms of planning, might provide a suitable forecast tool for the fishing industry.

ACKNOWLEDGEMENTS

This work had support from Instituto Politécnico Nacional, and was project CGPI 20050794. Daniel Lluch-Belda was supported by a COFAA-IPN fellowship.

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