Penaeid shrimp landings in the upper Gulf of California in relation to Colorado River freshwater discharge

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A commercial trawl fishery in the upper Gulf of California provides the principle source of income for the coastal communities of the region, but catches of estuarine-dependent crustaceans and fish have declined in recent years (Hernan, 1997; Cudney-Bueno and Turk-Boyer, 1998). Declines in shrimp landings, mainly *Litopenaeus stylirostris* (formerly classified as *Penaeus stylirostris*) (Perez-Farfante and Kinsley, 1997) have been attributed primarily to over-exploitation of the resource and to viral diseases (Rosas-Cota et al., 1996; Hernan, 1997).

The Biosphere Reserve of the upper Gulf of California and Colorado River Delta was created in 1993 to address some fisheries management problems. A more fundamental problem, however, may be the lack of river flow after construction of upstream dams. Historic reductions in river discharge have caused dramatic increases in salinity in the estuary and changes in the distribution of nutrients (Alvarez-Borrego et al., 1975; Hernandez-Ayon et al., 1993). Since 1979, occasional flood releases have entered the upper Gulf of California by means of the Colorado River when upstream impoundments are filled (Glenn et al., 1996).

Effects of freshwater on penaeid shrimp population development are controversial (Garcia and Le Reste, 1981; Day et al., 1989), but recruitment of spawning stocks of white shrimp (*Penaeus setiferus*) has been positively correlated with river discharge in the southwestern Gulf of Mexico and has been attributed to an expansion in estuarine nursery habitat for white shrimp (Garcia, 1991). River discharge also can stimulate the migration of subadults from estuaries (Deben et al., 1990; Vance et al., 1998). Fishermen have a strong perception that shrimp and fish catches in the northern Gulf of California are related to freshwater discharge from the Colorado River (Cudney-Bueno and Turk-Boyer, 1998). To evaluate their perception we conducted a correlation analysis of shrimp landings at San Felipe Baja California (nearest shrimping station to the delta) with freshwater discharges from the Colorado River to the northern Gulf of California.

Materials and methods

Data on annual shrimp landings and number of trawlers legally fishing from San Felipe were obtained from the Secretary of Environment, Natural Resources and Fish (SEMARNAP), San Felipe, Mexico. Landings were available from 1977 and number of trawlers from 1982. The artisanal catches by small boats (pangas) or the significant illegal shrimp fishery are not accounted for in reported shrimp landings. Annual shrimp landings serve as indicators of the variability in the total landings and are reported for all species of shrimp, even though landings are >90% *L. stylirostris* in San Felipe (Rosas-Cota et al., 1996). Data on freshwater discharge of the Colorado River were from the Southerly International Border (S.I.B.) gauging station which is below the last diversion on the river and were obtained from the United States

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Bureau of Reclamation, Yuma, Arizona (Williams[1]). We assumed that this flow entered the delta and the upper Gulf of California.

Annual shrimp landings and landings divided by numbers of trawlers (normal catch per unit of effort, CPUE) were correlated with river flow and number of trawlers. Our normal CPUE was a crude approximation of stock abundance or catchability. We lacked actual fishing time (days, weeks, hours of net deployment), size frequency of the legal vessels, and number of small boats (pangas) fishing. We made landings lag river discharge by one year because the life cycle of shrimp from hatching to capture is approximately one year (Gracia-Pamanes[2]). Transformed river flow ($\log_{10}$) was tested for nonlinearity; then we conducted a multiple regression analysis to predict shrimp landings from variables that were individually correlated ($P<0.05$) with landings.

Results

Annual shrimp landings ranged from 701 metric tons (t) (1983–84) to 217 t (1992–93), decreasing significantly from 1977 to 1996 (r=0.78, $P<0.001$, Fig. 1A). The reported number of trawlers legally fishing from San Felipe ranged from a high of 59 in 1988 to a low of 20 in 1995 (Fig. 1B). Catch per unit of effort (CPUE) increased from 1982 to 1984, then markedly decreased back to the 1982–83 level in 1985, remaining low until 1993, after which a positive trend was achieved and the highest CPUE ever was recorded in 1995 (Fig. 1C). There were substantial flows (>700 million cubic meters, Mm^3) in 8 of the 21 years from 1976 to1996 and varied over 10^4-fold, ranging from 1 Mm^3 in 1990 and 1996 to 15,657 Mm^3 in 1984 (Fig. 1D). Highest volume occurred between 1980 and 1987 as a result of overflow from Lake Powell in the United States (Glenn et al., 1996). The flow spike in 1993 was due to releases from Painted Rock Dam on the Gila River in Arizona. Periods of significant river flow at the S.I.B. were closely matched to El Nino Southern Oscillation (ENSO) events that occurred in 1983 and 1993.

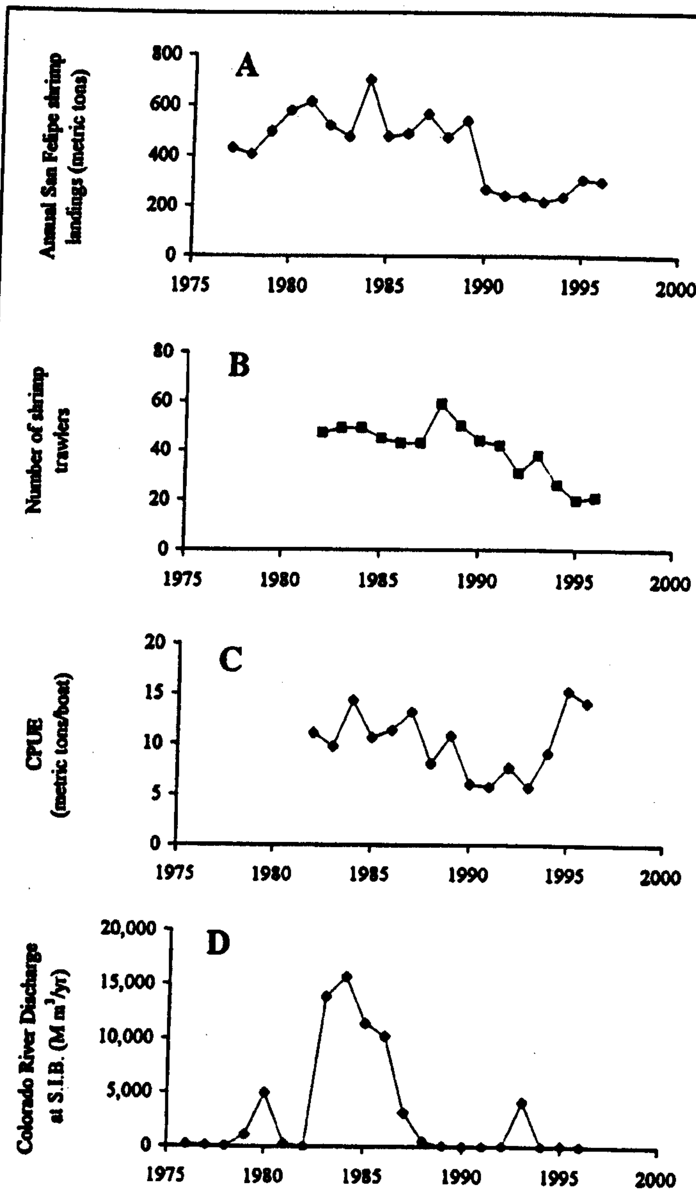

Figure 1

(**A**) Annual San Felipe shrimp landings (metric tons); (**B**) Number of shrimp trawlers fishing annually in San Felipe; (**C**) CPUE (metric tons/boat); (**D**) Colorado River freshwater discharge flow below the Southerly International Border (million m^3/yr).

Shrimp landings were significantly ($P<0.05$) correlated with same year river discharge, but $\log_{10}$-transformed river discharge in the year prior to shrimp harvest produced the highest correlation coefficient (r=0.67, $P<0.001$) (Table 1). The number of trawlers also significantly correlated with shrimp landings (r=0.77, $P<0.001$), as expected. The best correlation (r) of shrimp landings was the product

[1] Williams, B. 1998. United States Bureau of Reclamation, Yuma, Arizona. Personal commun.

[2] Garcia-Pamanes, F. C. 1992. Biologia reproductiva y dinamica poblacional del camaron azul Penaeus stylirostris en el Alto Golfo de California. Instituto de Investigaciones Oceanologicas, Universidad Autonoma de Baja California, Ensenada. Unpubl. final report.

Table 1

Correlation coefficients (r) and significance levels (P) from regression analysis relating San Felipe annual shrimp landings (1977–96) and CPUE (1982–96) to rainfall and discharge of the Colorado River at the Southern International Border. A "1-year lag" indicates that shrimp landings were paired with the previous year's river discharge in the correlation analysis.

Variable	Correlation with shrimp landings		Correlation with CPUE	
	r	P	r	P
River discharge	0.47	0.0362	0.25	0.3360
Log_{10} river discharge	0.54	0.0112	0.25	0.3368
River discharge (1-yr lag)	0.52	0.0127	0.34	0.1826
Log_{10} of river discharge (1-yr lag)	0.67	0.0006	0.38	0.1304
Number of shrimp trawlers	0.77	0.0003	0.18	0.4804
Log_{10} of river discharge (1-yr lag) × number of shrimp trawlers	0.80	0.0004	0.29	0.8771

of log_{10}-lagged river discharge and number of trawlers (r=0.80, P<0.001). CPUE was not significantly (P>0.05) correlated with river flow or number of trawlers (Table 1), nor with total landings (r=–0.26, P=0.31). The equation of best fit (0.64) for predicting shrimp landings took the form

$$Y = a + m(X_1X_2),$$

where X_1 = log_{10}-lagged river discharge (Mm^3/yr);
X_2 = number of trawlers;
Y = shrimp landings (t/yr);
M = the slope of the equation (1.67); and
a = the Y-intercept (232 t/yr).

Discussion

Our analyses represent a first attempt to identify relationships between variability in shrimp landings in the upper Gulf of California and factors influencing these landings. Total shrimp landings and the size of the shrimping fleet at San Felipe have declined over the past 15 years. Social and economic changes have affected shrimping. In the late 70s and early 80s shrimping was reserved for social units (cooperatives), with the result that privately owned shrimp trawlers were banned from the fishery. In addition, the government subsidized building of additional vessels and many new unskilled fishermen entered the industry. Then policies were reversed in the late 1980s, private boats returned, interest rates increased, and many of the shrimp trawlers were removed from the fleet.

We found a significant relationship (P<0.001) between total catch and the rate of freshwater discharge of Colorado River water into the marine ecosystem, although the mechanisms through which river discharge might affect the shrimp fishery are unknown. Lower salinity may improve the survival of early life stages by providing "enlarged nursery" protected habitat (Garcia, 1991), even though *L. stylirostris* and *P. californiensis* are generally considered euryhaline species (Hernan, 1997), having large numbers of postlarvae and juveniles in hypersaline habitats (Brusca, 1980; Page[3]). Salinity and nutrient gradients in the estuary and upper Gulf during river flows have not been reported to our knowledge.

Future plans for the Colorado River will likely decrease freshwater discharge into the estuary as more water is diverted upstream for farms and domestic use (Morrison et al., 1996). Our analyses suggest that decreases in river discharge to the delta and estuary may adversely affect shrimp landings. The United States and Mexican governments should initiate a research program on the effects of river flow on ecologically and commercially important species in the upper Gulf of California and incorporate these findings into a comprehensive management plan for the Biosphere Reserve as well as the Colorado River Basin at large.

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