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Shrimp Landing Trends as Indicators of Estuarine Habitat Quality

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Penaeid shrimp support three major commercial fisheries in the Gulf of Mexico. They are an estuarine-dependent species with life cycles that are completed within 1 yr. The stocks are fully exploited. Landings are independent of effort in that increased effort would not increase landings. Landings are therefore a direct measure of stock. Because the penaeids are annual species, landings are also a measure of recruitment. Since recruitment is dependent on habitat quality, landings are a measure of habitat quality and temporal trends in annual landings reveal trends in estuarine habitat quality. The landings trends indicate diminished habitat quality in Florida Bay since the mid-1980s. Landings for Louisiana and Texas reveal either increasing habitat quality or no change over the past 44 years.

INTRODUCTION

The commercial fisheries along the United States' Gulf of Mexico coast for brown (*Farfantepenaeus aztecus*), white (*Litopenaeus setiferus*), and pink (*Farfantepenaeus duorarum*) shrimp are based on stocks in which essentially all individuals are spawned, grow, reproduce, and die within one year (NOAA, 1992). Spawning occurs offshore and postlarvae are carried by currents into estuaries where they grow to subadults that later migrate offshore to spawn (NOAA, 1992). Although the fisheries are fully exploited, recruitment overfishing has not occurred and recruitment is not related to spawning biomass (Klima et al., 1990; Nance, 1993; Haas et al., 2001). Therefore, recruitment to the fishery is primarily a function of habitat quality within the estuaries where postlarvae grow to subadults.

Annual commercial landings are summarized in Table 1. Data, by year and month, for all shrimp fisheries since 1960 are available from NOAA in the annual "Fisheries of the United States" published by the National Marine Fisheries Service. Data since 1990 are also on the internet at <http://www.st.nmfs.gov>. Commercial landings represent the biomass caught and brought to shore by commercial fishermen. The major Gulf shrimp fisheries are fully exploited, meaning that landings are large enough to be independent of effort (NOAA, 1991; Nance and Harper, 1999; Nance, 2002). Because fishing effort is sufficiently large to harvest the available biomass produced by each year's shrimp population, the landings are an annual measure of stock.

So four central facts apply: 1) penaeid shrimp are an annual species so stock size measures annual recruitment, 2) landings measure stock size, 3) recruitment is independent of spawning biomass, and 4) annual recruitment depends on habitat quality in the estuaries where postlarval shrimp grow to subadults. Given these facts, landings are a measure of habitat quality. While we cannot usually quantify the connection between landings and habitat quality, it follows from the above that trends in annual landings reflect trends in habitat quality. The landings data maintained since 1960 for the Gulf of Mexico shrimp fisheries provide long time series to examine for trends.

METHODS

Landings data, reported by state, are an indicator of estuarine habitat quality in that state only if shrimp landed were caught in waters of that state. Shrimpers, though, can land shrimp taken from waters of other states. Almost all the landed Gulf pink shrimp are caught off the Dry Tortugas. Because the reported landings of pink shrimp in other Gulf States are very small compared to Florida (Table 1), the Florida landings can be equated with the Florida catch. For the brown and white shrimp fisheries it was necessary to examine correlations between landings and catch data. The latter were provided for the Gulf of Mexico by the National Marine Fisheries Service laboratory in Galveston, Texas for each of 18 statistical areas in the Gulf. Catches within areas adjacent to a state's coast were assigned to that state and summed to the annual catch by state. Over the 44-year period from 1960 to 2003 the correlation coefficients were greater than 0.95 for brown and white shrimp off Louisiana and for browns off Texas. The coefficients fell to 0.73 for white shrimp off Texas. Combining the Louisiana and Texas catch and landing data for white shrimp led to a coefficient of 0.99. Conversely, the brown shrimp landings for Alabama and Mississippi, two states with relatively low landings compared to Louisiana and Tex-

TABLE 1. Forty-four-year mean annual landings (metric tons) for brown, white, and pink shrimp fisheries in states along the Gulf of Mexico.

State	Years	Brown	White	Pink
Texas	1960–2003	15,201	5,369	129
Louisiana	1960–2003	12,449	12,197	8
Mississippi	1960–2003	2,233	681	64
Alabama	1960–2003	3,091	801	274
Florida (Gulf)	1960–2003	411	340	5,283

as, were not correlated with catch and combining the two states yielded a correlation of only 0.6. This is statistically significant ($P < 0.01$) but assigns only 36% of the landings in the combined states with catch off those states.

RESULTS

Annual landings data were examined for brown and white shrimp off Louisiana and Texas and for pink shrimp in Florida (Gulf Coast). Linear correlations between landings and year (i.e., linear trends) were calculated pair-wise for each species by state. The data could have been too variable to reveal temporal trends but the results in Table 2 show significant ($P < 0.05$) positive trends for brown shrimp landed in Louisiana (Fig. 1) and white shrimp landed in Louisiana and Texas, and a significant negative trend for pink shrimp in Florida (Gulf Coast). The increasing trends could be because of fishing effort; harvests in the early 1960s were not quite to their present fully exploited levels (Nance, 2001). Calculated trends just since 1970, however, still yielded significant positive trends for white shrimp in Louisiana and Texas and a negative trend for Florida (Gulf Coast) pink shrimp.

DISCUSSION

The correlations between landings and year in Table 2 are statistically significant but leave most of the overall variability attributable to other sources of variation. Annual variations in water levels, temperature, salinity, and any other naturally changing aspects of habitat quality can cause annual landings to vary (Zein-Eldin and Renaud, 1986; Sheridan, 1996; Haas et al., 2001). However, because they are either random or cyclic, variations in natural factors affecting shrimp stocks cannot create linear trends in landings. Habitat degradation caused by humans would be manifest in either a long-term monotonic decrease in landings or by an abrupt decrease whereby degradation proceeds to the point where habitat can no longer support historical landings.

The decreasing trend in Florida (Gulf) from the mid-1980s to mid-1990s (Fig. 2) has been attributed to habitat changes such as reduced freshwater flow from the Everglades and losses of seagrass in Florida Bay (Ehrhardt and Legault, 1999; Browder, et al. 1999). In the late 1990s landings rose to about their long-term average but were low again for 1999–2003. An alternative explanation is that the landings go through a sinusoidal cycle of as yet unquantifiable periodicity. If it were possible to find environmental variables that would explain the overall variability in the record and, especially, account for any possible natural cycles, the record would be a stronger measure of any man-made influences on habitat quality.

The temporally increasing landings in the western Gulf States have received little attention. While one cannot unequivocally conclude that there is a corresponding increasing

TABLE 2. Spearman correlation coefficients of landings vs year for shrimp fisheries where landings are a measure of catch in state waters. With $n = 44$, coefficients with absolute values greater than 0.39 are significant ($P < 0.05$).

State	Years	Brown	White	Pink
Texas	1960–2003	0.297	*0.635*	—
Louisiana	1960–2003	*0.652*	*0.650*	—
Louisiana and Texas combined	1960–2003	—	*0.674*	
Florida (Gulf)	1960–2003	—	—	*−0.545*

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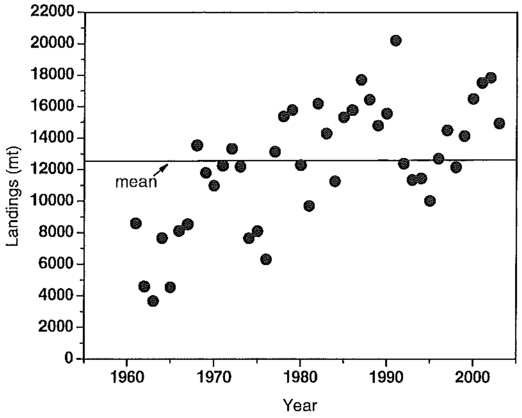

Fig. 1. Annual landings of brown shrimp in Louisiana.

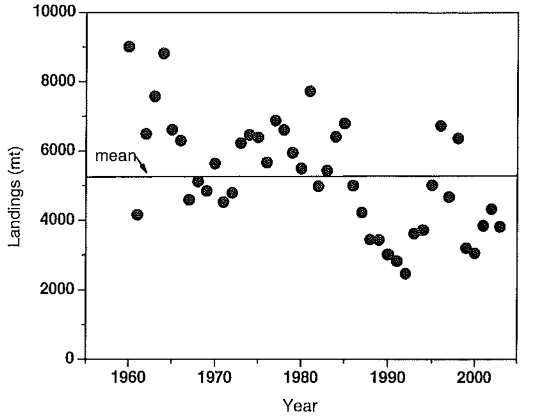

Fig. 2. Annual landings of pink shrimp on the Gulf Coast of Florida.

trend in estuarine habitat quality in Texas and Louisiana, there is a proposed mechanism for such an increase. Zimmerman et al. (2001) proposed that wetland subsidence and corresponding sea level rise would benefit shrimp as it formed wetland channels and effectively increased the size of shrimp habitat. Minello et al. (2002) have shown that shrimp densities in marshes vary inversely with distance from water's edge and increase as edge is created with channelization. The absence of decreasing trends indicates that habitat quality for shrimp has not been decreasing. For example, it is apparent in Texas (Fig. 3) that shrimp landings are not responding to increased population pressure (U.S. Census Bureau, 2002; M. Perry, pers. comm.) on the coastal zone. At least to date, that pressure has not diminished estuarine habitat quality for shrimp.

Demonstrated dependence of landings on habitat quality.—Because the species are annual, and because landings are independent of effort and thus a measure of stock size, we concluded that landings are also a measure of estuarine habitat quality. The validity of this conclusion is evident in the time series of annual pink shrimp harvest in North Carolina. This fishery, averaging about 450 metric tons per year through 1992, is small in comparison with the major shrimp fisheries, but in this case there is a strong connection between harvest and a particular measure of habitat quality.

Hettler and Chester (1982) found a high correlation for 1962 through 1981 between spring (January through July) harvests of pink shrimp in North Carolina and the coldest 2-wk average water temperature in the prior winter (December through February) measured at Beaufort, North Carolina. The lower the temperatures, the lower the harvest, presumably because fewer shrimp survived the cold snap. With 10 more years of data, the correlation remained high (Hettler, 1992). The correlation was high enough to justify calculating a regression with temperature as the sole independent variable. The regression [landings (metric tons) = 83.7T (C) − 245, $r^2 = 0.80$] from 1962 through 1992 is remarkable in that a single measure of habitat quality accounted for 80% of the variation in the highly variable harvest (Figs. 4a and b).

This high correlation may be attributable to North Carolina's being at the northern extreme of the range of pink shrimp, making the shrimp in this area particularly vulnerable to temperature (Myers, 1998). There have been attempts to correlate the major shrimp har-

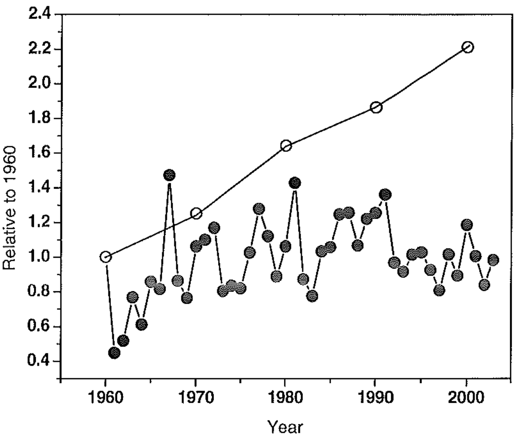

Fig. 3. Annual landings of brown shrimp in Texas and decadal population counts in Texas coastal counties.

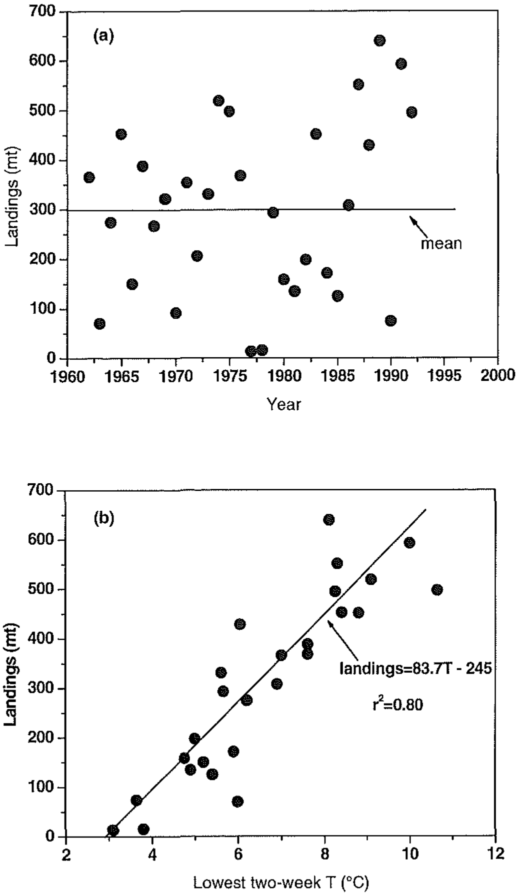

Fig. 4. Annual spring (January through July) landings of pink shrimp in North Carolina vs (a) year and (b) lowest 2-wk average water temperature measured at Beaufort, NC.

vests in Gulf States with estuarine water level, temperature, and salinity during critical periods of postlarval development (Zein-Eldin and Renaud, 1986; Sheridan, 1996; Browder et al., 1999; Ehrhardt and Legault, 1999; Haas et al., 2001; Zimmerman, 2002). None have been as strikingly successful as the observations for North Carolina pink shrimp (Hettler and Chester, 1982). However, although we cannot directly connect landings with any one measure of habitat quality (except for North Carolina pinks) we can claim that trends in landings indicate trends in habitat quality. This observation is of considerable utility because landings data have been collected since 1960 and continue to be collected as a standard component of fishery management.

Offshore processes.—We have attributed annual recruitment success of brown, white, and pink shrimp to estuarine habitat quality and have not considered the offshore portion of their life history from spawning to larvae being carried into estuaries. The assumption here, which seems justified, is that sufficient numbers of larvae reach estuaries every year to meet the needs of any level of recruitment. Since recruitment is independent of spawning biomass (Klima et al., 1990; Nance, 1993; Haas et al., 2001), there are a sufficient number of larvae spawned. The planktonic step whereby larvae are carried into estuaries would seem critical to recruitment. Yet, in the case of North Carolina pink shrimp, where 80% of the annual variability in landings is because of a single characteristic of estuarine habitat quality, offshore process are at best of minor consequence. Haas et al. (2001) include offshore processes in their statistical analyses of factors affecting stocks of Louisiana brown shrimp but found them unimportant. It may be that so large a number of larvae are annually produced by these very fecund species [100,000–1,000,000 eggs per female (TPWD, 2004)] that the larval stage is not a critical stage in recruitment.

Maintaining the record.—The impetus for this analysis was the remarkably strong correlation through 1992 between pink shrimp harvests in North Carolina and lowest 2-wk mean water temperature in winter. That correlation does not extend beyond 1992. Shrimp landings for 1994 through 1999 were not recorded by species. The reported pink shrimp landings (January through July) for 1993, 2000, 2001, 2002, and 2003 were correlated with winter temperature (r^2 = 0.91) but were less than half of their expected value based on the 1962–1992 regression.

The low likelihood of five sequential harvests being so far below expectations means the original regression is no longer valid. This would imply a degradation of habitat quality except that in 1993 the method of surveying landings changed from government agents counting shrimp at fishing ports to trip tickets submitted by dealers. It is the self-reporting of landings and not the condition of pink shrimp stocks that probably accounts for the model's inability to estimate landings after 1992. Recently reported landings for brown and white shrimp in North Carolina are not historically low. However, June and July, two of the months that contribute to the spring harvest of pink shrimp, are also months of very high landings of brown shrimp. There is no economic reason for North Carolina dealers to differentiate

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pink from brown shrimp and if only about 10% of the "browns" were actually "pinks" the spring landings for pink shrimp would fall within the 1962–1992 regression.

Hopefully, this problem is unique to a "minor" fishery and future annual landings recorded for Texas and Louisiana brown and white shrimp fisheries and for the Florida (Gulf Coast) pink shrimp fishery will continue to be compatible with the existing 44-yr record.

Conclusion

Records of landings of penaeid shrimp by the major fisheries along the Gulf of Mexico have been maintained since 1960 for commercial purposes. From the viewpoint of monitoring estuarine habitat quality this is essentially a "free" data set. So far it appears that estuarine habitat quality for shrimp may be decreasing in Florida Bay and either not changing or increasing in Louisiana and Texas. So long as record-keeping remains consistent with the present system, conclusions about future trends in habitat quality can be determined from these relatively inexpensive data.

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