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Note

Linking hypoxia to shrimp catch in the northern Gulf of Mexico

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Abstract

Wide spread and reoccurring hypoxia has been observed in the northern Gulf of Mexico since routine monitoring began in the 1980s. Although the potential ecological effects of hypoxia (habitat loss, mortalities) are well known, there is relatively little information linking hypoxia in the northern Gulf of Mexico to fisheries decline. Previous analyses have shown a negative relationship between hypoxic area and brown shrimp (*Farfantepenaeus aztecus*) catch for the Texas and Louisiana coasts combined from 1985 to 1997. Extending these analyses with data through 2004, we found that the correlation between hypoxic area and landings holds ($r = -0.52$), plus there was a significant negative relationship ($r = -0.59$) between hypoxia and shrimp landings for the Texas coast alone. We hypothesize that this pattern is not seen in the Louisiana fishery alone because of differences in fisheries practices (inshore vs. offshore) between Louisiana and Texas.

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1. Introduction

Hypoxia is a common water quality problem that can severely impact aquatic ecosystems. Although hypoxia (defined as dissolved oxygen concentrations $\leqslant 2\ \mathrm{mg\ L^{-1}}$) can occur naturally, it is often a symptom of degraded water quality resulting from anthropogenic activities (e.g. nutrient pollution, eutrophication). Over the last few decades, there have been increases in the frequency, duration, and spatial extent of hypoxic events, and hypoxia is now recognized as one of the most significant threats to fisheries production worldwide (Breitburg, 2002; Diaz and Nestlerode, 2004). Despite the magnitude of the problem, a clear view of the impacts of hypoxia on living resources is lacking in many aquatic systems.

The northwestern Gulf of Mexico shelf is the location of the largest hypoxic zone in the coastal US. The areal extent of the Gulf's seasonally recurring hypoxic zone, monitored in mid-summer since 1985, has increased from an average of 6900 $\mathrm{km^2}$ from 1985–1992 to 13,600 $\mathrm{km^2}$ from 1993–2004, with a peak of 22,000 $\mathrm{km^2}$ in 2002 (Rabalais et al., 1999; Rabalais and Turner, 2006). The northwestern Gulf of Mexico also supports some of the nation's most important commercial and recreational fisheries, which annually generate over $2 billion. Texas and Louisiana are national leaders in US commercial shrimp landings. In 2004, these states landed 64% of the nation's shrimp tails (NOAA, 2006).

The Gulf's hypoxic zone presently occurs in an area that in the 1950s and 1960s was the most productive fishing grounds in the Gulf of Mexico (Moore et al., 1970) Motile organisms such as shrimp avoid hypoxic waters (Zimmerman and Nance, 2001), and Craig et al. (2005) found that hypoxia resulted in a loss of habitat and a shift in spatial distribution of subadult brown shrimp (*Farfantepenaeus aztecus*) to waters both inshore and offshore of the hypoxic zone. Brown shrimp avoidance of the hypoxic zone causes them to aggregate on the periphery of the zone, where temperatures may be suboptimal for growth (Craig and Crowder, 2005). Craig et al. (2005) estimated that the hypoxic zone has resulted in about a 25% habitat loss for brown

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shrimp that occur on the Louisiana shelf west of the Mississippi delta. They hypothesized that the change in spatial distribution may lead to decreases in metabolic scope due to exposure to higher than optimal temperatures (inshore displaced populations) or lower than optimal temperatures, moderately low dissolved oxygen concentrations, and possibly lower food supply (offshore displaced populations). Consistent with the hypothesis, Craig and Crowder (2005) cite their unpublished data suggesting a relationship between Gulf hypoxia displacement of brown shrimp into suboptimal temperature conditions and reduced weight, and cite earlier studies showing a long-term decrease in brown shrimp size in the Gulf (Diaz and Solow, 1999).

Two species dominate the shrimp fishery in Louisiana and Texas, brown shrimp and white shrimp (*Litopenaeus setiferus*). These species vary somewhat in temperature and dissolved oxygen optimal ranges for growth, with brown shrimp more sensitive to high and low temperatures (Etzold and Cristmas, 1977) and low oxygen (Renaud, 1986). For example, based on laboratory experiments, brown shrimp were found to avoid waters with dissolved oxygen concentrations <2 mg L^{-1} and white shrimp avoid concentrations <1.5 mg L^{-1}. Also, the species' life cycle patterns and consequently habitat preferences differ, and white shrimp primarily occupy waters inshore of brown shrimp, which are more dependent on offshore habitats (Zimmerman and Nance, 2001). Therefore, long-term increases in hypoxic zone area would be expected to have a greater impact on brown than white shrimp fisheries (Zimmerman and Nance, 2001). As evidence for species differences in hypoxic zone influence, Zimmerman and Nance (2001) cited the negative relationship between hypoxic zone area and brown shrimp catch during a period (1985–1998) of Gulf hypoxia expansion, while no association with white shrimp catch was found.

Another important factor in evaluating the impacts of hypoxia on Gulf shrimp fisheries is the difference in fishing protocols between Louisiana and Texas industries (Zimmerman and Nance, 2001). In Louisiana, most of the shrimp catch comes from trawls on the inner shelf. In Texas, the seasonal closure prohibits fishing from mid-July through mid-May so that juvenile can grow to adults (Nance et al., 1994). Therefore, Texas fisheries management targets brown shrimp populations that are more mature and farther offshore than populations caught in Louisiana fisheries. One implication is that the Louisiana fishery would be expected to be less impacted by hypoxia because the fishery includes shrimp taken before they reach the offshore area.

Potential effects of hypoxia on shrimp production and spatial distribution may have consequences for shrimp harvest. In examining the relationship between hypoxic zone area and shrimp catch from 1985 to 1997, Zimmerman and Nance (2001) found a significant negative relationship ($P = 0.02$) when the brown shrimp catches from both Louisiana and Texas fisheries were combined. A significant relationship with hypoxic zone area was not found when the brown shrimp catch from Texas was analyzed separately, and only weakly negatively related based on the Louisiana catch alone ($P = 0.10$). Also, in contrast to brown shrimp, no statistically significant relationships were found between hypoxic zone area and white shrimp annual catch.

2. Results

Zimmerman and Nance (2001) examined the correlation between shrimp catch in the Gulf of Mexico and the size of the annual hypoxic zone over the 13-year period, 1985–1997. Available data now allow correlations to be examined for the 19-year period of 1985–2004. With the readily available landings data (<http://www.st.nmfs.gov/st1/commercial/>) for brown and white shrimps and annual estimates of the size of the hypoxic zone (N.N. Rabalais, pers. comm., 2004) the results (Table 1) confirm those of Zimmerman and Nance in that there is no correlation of hypoxic area with landings of white shrimp or with landings of brown shrimp in Louisiana but there is a significant correlation with the total combined landings in Texas and Louisiana (Fig. 1). Unlike Zimmermann and Nance, we did find a significant correlation between the hypoxic area and brown shrimp landings in Texas alone and no correlation between hypoxic area and landings in Louisiana alone.

Zimmerman and Nance limited their regression to brown shrimp caught off Louisiana and Texas (not landed in Louisiana and Texas) and to the catch in the months of July and August. Doing so requires obtaining data from the National Marine Fisheries Service (NMFS) laboratory in Galveston, Texas, rather than using data at the NOAA/NMFS website where monthly data extend back only to 1990. The catch and landing data are very highly correlated (O'Connor and Matlock, 2005) and since 1985 reported catch has averaged only 3% more than reported landings. So using either catch or landings data in the context of this paper makes little difference. The corresponding regression of July + August catch for 1985–2004 (after converting

Table 1
Correlation coefficients between shrimp landings and size of hypoxic zone in the Gulf of Mexico over the period 1985–2004 ($n = 19$, no hypoxic zone data for 1989)

Species/State	Correlation (Pearson)	Correlation (Spearman)
Brown shrimp/LA	−0.25	−0.23
Brown shrimp/TX	**−0.59**	**−0.61**
Brown shrimp/LA and TX	**−0.52**	**−0.50**
White shrimp/LA	−0.29	−0.20
White shrimp/TX	0.10	0.05
White shrimp/LA and TX	−0.22	−0.20

Coefficients indicating significant correlations ($p < 0.05$) are shown in bold type. Parametric (Pearson) and non-parametric (Spearman) correlation coefficients are similar indicating that the parametric correlation is not influenced by extreme values.

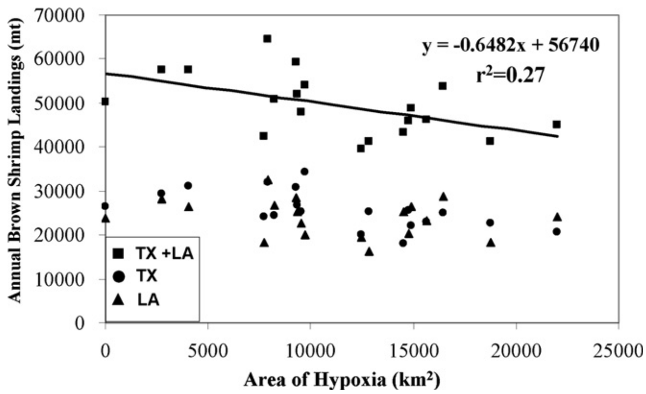

Fig. 1. Scatterplots of brown shrimp landings (1985–2004) in Louisiana and Texas and in the combined states versus the size of the hypoxic zone in the Gulf of Mexico. Data for landings are available from 1978–2004 from NOAA at (http://www.st.nmfs.gov/st1/commercial/). The area of the hypoxic zone has been estimated annually since 1985, except for 1989 (pers. comm. N.N. Rabalais 2004).

NMFS–Galveston data from heads-off to heads-on) versus hypoxic area is

$$\text{Catch(mt)} = 18425 - 0.214\ (\text{hypoxic area, km}^2)\ r^2 = 0.32. \quad (1)$$

Comparison with the regression based on annual data (Fig. 1),

$$\text{Landings(mt)} = 56740 - 0.648\ (\text{hypoxic area, km}^2)\ r^2 = 0.27 \quad (2)$$

shows a higher correlation over July + August than over the entire year but that about 70% of the catch and landings occurs in other parts of the year.

3. Discussion

Nutrients that fuel the Gulf of Mexico hypoxia are mostly derived from fertilizers applied in the watershed of the Mississippi River (The Mississippi River Gulf of Mexico Watershed Nutrient Task Force, 2001). We found a negative correlation between the size of the annual hypoxic zone and landings of brown shrimp, confirming and extending the findings of Zimmerman and Nance (2001). Unlike Zimmerman and Nance, we found a significant correlation when analyzing the Texas catch alone. The effect of expanding hypoxia on Texas, but not Louisiana, brown shrimp landings is consistent with differences in fishery practices; Texas brown shrimp landings occur further offshore than Louisiana, coinciding closer to the hypoxic zone.

While the correlation between brown shrimp landings and hypoxic area is statistically significant it only accounts for 27% of the variation in landings. Any increases in landings that could be achieved through controls on nutrient inputs to the Mississippi River might be lost among other factors affecting the harvest. Also, while correlation does not prove cause and effect, serial correlations can be particularly misleading. For both the hypoxic area (increasing with time) and the Texas brown shrimp landings (decreasing) there are statistically significant correlations with year over the period 1985–2004. These could be independent trends with the Texas shrimp landings due to secular changes in the estuarine habitat (O'Connor and Matlock, 2005) rather than being related to the offshore hypoxia. For total landings of Louisiana and Texas together there is no correlation with time so the correlation with hypoxic area is not the result of simultaneous serial correlations.

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