Effects of Freshwater Flooding on Eastern Oyster Populations in a Texas Estuary

Norman W. Boyd, *Coastal Fisheries Branch, Texas Parks and Wildlife Department, P.O. Box 688, Port O'Connor, TX 77982*

Gary Matlock, *National Marine Fisheries Service, 1315 East-West Highway, Silver Spring, MD 20910*

Lawrence W. McEachron, *Coastal Fisheries Branch, Texas Parks and Wildlife Department, 100 Navigation Circle, Rockport, TX 78382*

C. E. Bryan, *Coastal Fisheries Branch, Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, TX 78744*

Abstract: Relative abundance of Eastern oysters (*Crassostrea virginica*) was monitored before, during, and after a record flood in a Texas estuary. Salinities were reduced to <5 ppt over a large portion of the estuary for 4 months. Eastern oyster mortality was near 100%. Spat set was documented 9 months after flooding ceased and the oyster population had recovered to preflood levels 15 months later, 25 months after flooding ceased. A Ricker recruitment curve was fitted to the spawner-recruit data and explained 20.8% of the variation in number of spat.

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Estuaries are typically very dynamic environments and the biota inhabiting them have evolved wide tolerance limits to abiotic factors. Large salinity fluctuations characterize many estuaries and require significant biotic adjustments. These adjustments are particularly difficult during freshwater floods when salinities may drop to near freshwater levels for extended periods. When these near freshwater conditions prevail, mobile animals can move to more suitable areas whereas sessile animals such as Eastern oyster must tolerate prevailing conditions or die.

Salinity tolerance of Eastern oysters is affected by prevailing water temperatures. At optimum temperatures of about 10°–30° C, Eastern oysters can tolerate salinities of 3.0–43.5 ppt (Loosanoff 1953, Copeland and Hoese 1966, Quast et al. 1988). Optimum salinity range for adults is 16–24 ppt (Chatry et al. 1983, Hoffstetter 1983); feeding is reduced below 10 ppt (Hopkins 1936, Butler 1949, Loosanoff 1953). Optimum spat set in Galveston Bay, Texas, occurs between 17 and 24 ppt and is reduced below 8 ppt (Hoffstetter 1983). However, because tolerance of low salinity by these animals is inversely related to temperature, they are better able to withstand low salinities if temperatures are also low (<10° C). Stress from extended periods of low salinity is exacerbated by the high water temperatures usually encounterd during summer months (Hoffstetter 1977). Severe mortality can result if temperatures above 25° C and salinities <2 ppt occur simultaneously and persist for 2–4 weeks.

Eastern oyster populations range from the Gulf of St. Lawrence in the northwest Atlantic Ocean to the Yucatan Peninsula in the Gulf of Mexico (Andrews 1981). Along the Texas coast large oyster communities are generally restricted to the moderate salinities of the bays north of the Nueces Estuary (Corpus Christi Bay System). Salinity and temperature regimes in the Guadalupe Estuary (San Antonio Bay System) are usually within the optimum range for Eastern oysters. This estuary, consisting of 3 major and 6 minor bays, contains 803 ha of mapped reefs which support a commerical fishery. The oyster population in this bay system is periodically devastated by freshwater flooding from the Guadalupe River (Crowe 1982, Marwitz and Bryan 1990). During June 1987 the bay system was inundated by a record freshwater inflow. The combined inflows for the Guadalupe Estuary for June 1987 and for the entire year were the highest monthly and yearly combined inflows recorded for the estuary during 1941–1987 (Solis in press). This severe and prolonged flood event dramatically reduced salinities in the estuary causing mass mortality of Eastern oysters. Commercial oyster harvest from the Guadalupe Estuary for 1987 decreased by 94% compared to 1986. The 1988 harvest was only 0.5% of the 1986 pre-flood harvest (Johns 1990).

The Texas Parks and Wildlife Department (TPWD) initiated a coastwide routine oyster reef monitoring program in 1986 (Mambretti et al. 1990). This program afforded the opportunity to describe the effects of the 1986–87 flood on oysters in the San Antonio Bay system and subsequent recovery. The objectives of the present study were to 1) document the response of the San Antonio Bay system Eastern oyster population to the 1987 freshwater flooding and 2) to determine the spawner-recruit relationship.

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Methods

All samples were collected from the San Antonio Bay system. This bay system lies on the central Texas coast and consists of 3 major bays and 6 minor bays. The largest, San Antonio Bay, is centrally located and receives inflow from the Guadalupe River. Mesquite Bay lies adjacent to and southwest of San Antonio Bay. Espiritu Santo Bay lies adjacent to and northeast of San Antonio Bay and receives seawater exchange from the Gulf of Mexico via Pass Cavallo.

A stratified random sampling program to monitor Eastern oyster populations was initiated by the TPWD in January 1986 (Mambretti et al. 1990). All reefs (bay bottom forming oyster reefs ≥0.2 m higher than adjacent bottom for a continuous distance of ≥91.4 m long and 0.5 m wide) in the 55,158-ha San Antonio Bay system (Matlock and Osborn (Ferguson) 1982) were used to select sample sites. Oyster dredge sample sites in each reef area were randomly selected from bay grids (1 minute latitude by 1 minute longitude). Each grid (1 square nautical mile) was divided into 144 5-second "gridlets" and all gridlets containing reef were used to randomly choose a sample site in that grid. Twenty-six samples were collected each month by pulling a "Louisiana Style" 8 tooth dredge with 76-mm bag mesh size linearly for 30 seconds in the selected gridlet. The 30-second tow is more sensitive to fluctuation in oyster abundance than longer tows (Doerzbacher and Meador 1989). All monthly catches were converted to *N*. caught/hour as a measure of relative abundance for all size groups. No more than 1 grid was duplicated in any month and gridlets were not duplicated.

All live oysters ≥5 mm (hinge to bill) were grouped into spat (5–25 mm), small (26–75 mm), or market (>75 mm) sizes. Number of spat was determined by counting the number present on 5 randomly selected live and dead shells and extrapolating to the remainder of the sample. Small and market oysters were determined by counting their numbers in a random subsample of no more than 19 live oysters from each 30-second sample and extrapolating to the remainder of the sample. Bottom salinity and water temperature were measured at the time of each sample.

The relationship between spawners (P) and recruits (R) for Eastern oysters in the San Antonio Bay system following the 1986–87 flood was estimated using data collected during August 1987 through December 1991. Simple linear regression analysis (Sokal and Rohlf 1981) using LOTUS 1-2-3 (LOTUS Devel. Corp., Cambridge, Mass.) and the equation $P = a + bR$ was used to determine if recruitment was directly related to the number of spawners throughout this period. Ricker and Beverton-Holt recruitment curves were also fit to the data using non linear least squares techniques contained in FISHPARM (Prager et al. 1989).

To estimate the spawner-recruit relationship, P at time t_i and R at some subsequent time (t_{i+n}) must be determined. Number of Eastern oyster spawners present in the San Antonio Bay system was estimated using the total monthly catch of market oysters. These animals were sufficiently large (old) to spawn (Quast et al. 1988). Because the sex ratio of these oysters was not determined it was assumed the proportion of females in the population did not vary among months. Eastern oysters spawn in Texas bays throughout the year with peak spawning in June or July when temperatures are 25° C or greater (Quast et al. 1988). However, Eastern oyster spawning in the San Anonio Bay system during 1986–91 appeared to be more evenly distributed throughout the year than that reported by Quast et al. (1988). For this reason, data from all months after July 1987 (when flooding ended) were used. Number of spat caught each month in TPWD samples was used as the number of recruits. Eastern oysters reach 15 mm (midpoint of spat size class) in 1 to 3 months (Quast et al. 1988). Therefore, the spawner-recruit curves were separately fitted to the number of spawners in month t (P_t) and the subsequent number of recruits 1, 2, or

3 months later (R_{t+1}, R_{t+2} and R_{t+3}). The curve with the highest adjusted r^2 was considered the best fit.

Results

Flooding from the Guadalupe River in 1986 and 1987 drastically reduced both salinity and the oyster population (Fig. 1). Salinities were reduced to <5 ppt over a large portion of the estuary. Oyster populations were reduced by >99%, from 3,517 oysters/hour in January 1986 to 5/hour in March 1987. After flooding ceased in September 1987, salinities increased to pre-flood levels within 2 months. Oyster populations began to increase in June 1988, 1 year after flooding ceased. Populations

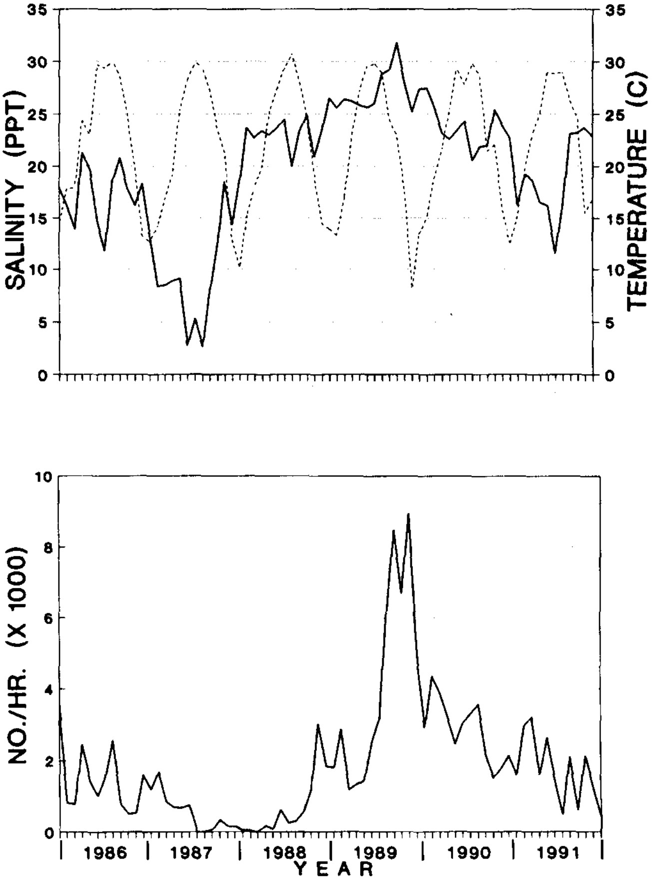

Figure 1. Mean monthly salinities (solid line), temperatures (broken line) and Eastern oyster catch rates for the Guadalupe Estuary during 1986–1991.

did not recover to pre-flood levels until September 1989, 2 years after flooding ceased (Fig. 1). This temporal abundance pattern was apparent in all size classes beginning first with spat and proceeding to larger sizes through time.

The degree to which the flood affected salinity and oyster populations varied among areas within the bay system and was inversely related to distance from the river mouth. Average monthly salinities in the central portion of the estuary (San Antonio Bay) decreased to <5 ppt for 4 months (June–September 1987) and were near 0 ppt in some areas (Fig. 2). Water temperatures in this area were >27° C for these 4 months. Consequently, this area experienced the most severe mortalities (>99%); live oysters were essentially eliminated for 7 months (August 1987–February 1988) (Fig. 2). Salinities in the southwestern portion of the bay system (Mesquite Bay) and northeastern portion (Espiritu Santo Bay) also decreased during flooding, but did not drop below 5 ppt or remain low for as long as in the central portion of the estuary (Fig. 3). Eastern oyster mortality was also detected in these areas, but not to the extent experienced in the central portion (Fig. 3). Mortality in these peripheral areas was primarily among spat.

Recovery of Eastern oysters also varied among areas within the estuary. Although TPWD samples contained no live oysters in San Antonio Bay from August 1987 through February 1988, anecdotal information indicates that at least 2 unsampled areas contained some live oysters. Live oysters were observed by TPWD personnel in shallow (<0.5 m) shoreline areas in this bay. Mortalities were heaviest in San Antonio Bay, and the recovery was most obvious there. Spat and small oyster

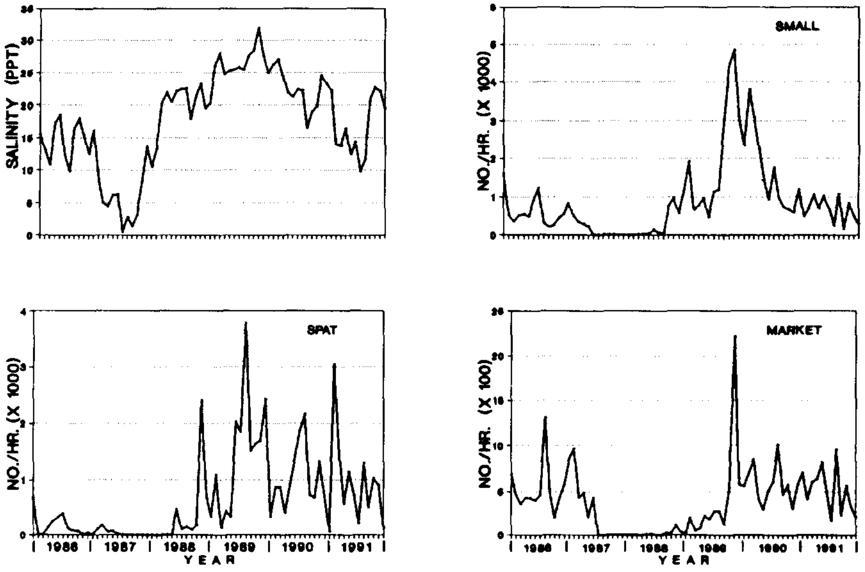

Figure 2. Mean monthly salinities and Eastern oyster catch rates for San Antonio Bay during 1986–1991.

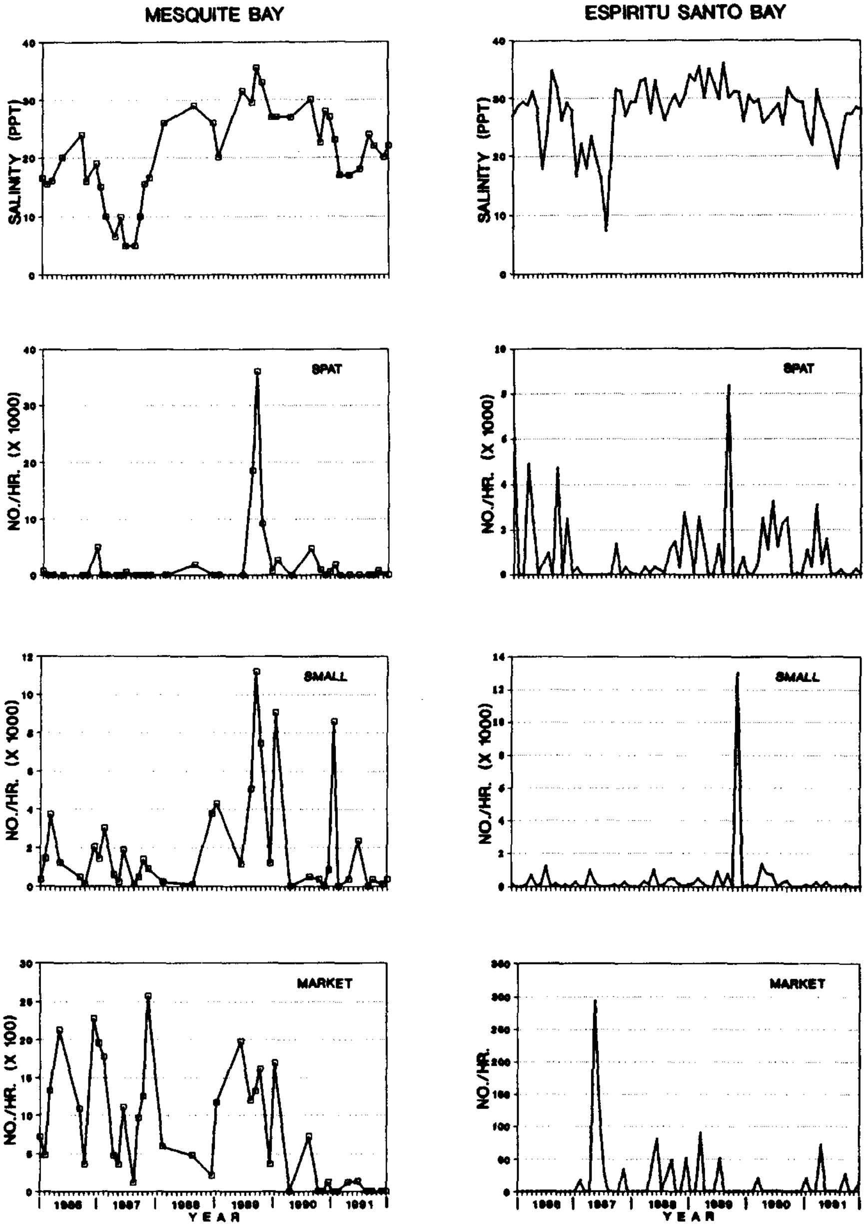

Figure 3. Mean monthly salinities and Eastern oyster catch rates for Mesquite and Espiritu Santo Bays during 1986–1991. Samples were not collected every month in Mesquite Bay. Open squares indicate sample months.

populations recovered to pre-flood levels by November and January 1989, respectively, over 1 year after the flood. Market oysters did not reach pre-flood levels until October 1989, 25 months after flooding ceased. In the Mesquite and Espiritu Santo bays, spat populations reached pre-flood levels by August and September 1989, respectively, about 2 years after the flood event. Small and market populations in these 2 areas suffered minor flood related mortalities. The Espiritu Santo Bay market oyster catch rates actually increased during the flood and remained higher than pre-flood levels until 1990, 30 months after the flood. However, the small and market populations of Mesquite Bay decreased in 1988 as a result of spat mortality in 1987.

There was a significant spawner-recruit relationship for Eastern oysters. Number of spawners collected each month was significantly related to the number of spat collected 1, 2, and 3 months later (Table 1). However, the relationship was not linear (Fig. 4). None of the simple linear regressions explained a significant amount of the variation in the spawner-recruit data. The Beverton-Holt recruitment curve also failed to fit the data since convergence criteria were not met for any data set. The best Ricker recruitment curve fit (based on r^2) was between number of spawners and number of spat 2 months later (adjusted $r^2 = 0.208$, $F = 36.99$, $P < 0.01$). However, >79% of the variation in the data remained unexplained by the curve.

Discussion

Recovery of Eastern oyster populations experiencing a mass nortality apparently requires very few spawners if environmental conditions are suitable and sufficient habitat is available. This conclusion is supported by the following evidence. The statistically significant spawner-recruit curve indicated the density-independent limb of the Ricker curve was very steep ($a = 16.07$). Sampling indicated very few live oysters remained in San Antonio Bay after flooding, and they were located

Table 1. Results of fitting Ricker recruitment curves ($R = aPe^{(-\beta P)}$ to the number of Easter oysters >75 mm (spawners) collected in the San Antonio Bay system each month during July 1987 through December 1991 and the number of spat 5 to 25 mm collected 1, 2, or 3 months later. Where P is the number of spawners, R is the number of recruits, a is the fecundity constant, b is the density dependence parameter and e is the natural logarithm base.

Time lag (months)	*N*	a (Asymptotic SE)	β (Symptotic SE)	F	Adjusted r^2
1	53	15.520 (4.319)	0.0177 (0.0037)	33.45*	0.165
2	52	16.070 (4.260)	0.0175 (0.0034)	36.99*	0.208
3	51	21.360 (5.240)	0.0218 (0.0036)	36.15*	0.192

$^*P < 0.01$.

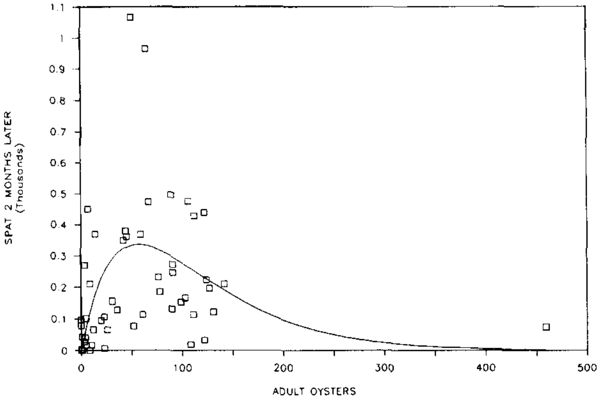

Figure 4. Relationship between the total number of adult (>76 mm) Eastern oysters (market oysters) collected in Texas Parks and Wildlife Department oyster dredges each month during July 1987 through December 1991 in the San Antonio Bay system and the total number of Eastern oyster spat (5–25 mm) caught 2 months later.

primarily in the peripheral areas, Mesquite Bay and in Espiritu Santo Bay near Pass Cavallo. Yet, enough spat were produced to bring the population back to pre-flood levels within 24 months after flooding. The few market oysters remaining in these peripheral areas were probably an important source of spat because there is documented evidence that water enters San Antonio Bay from both Mesquite Bay and Espiritu Santo Bay (Childress et al. 1975, TDWR 1978). This water movement pattern could have resulted in planktonic oyster larvae being carried from the parent stocks in Mesquite Bay and Espiritu Santo Bay into San Antonio Bay. The recovery was probably enhanced by increasing salinities after the flood and the availability of suitable substrate.

This study suggests the importance of Eastern oysters in these peripheral areas for maintaining a viable commercial fishery in the San Antonio Bay system. Future flooding from the Guadalupe River and resultant mass mortalities of Eastern oysters can be expected. Although few adults may be needed to repopulate the major part of the system, the geographic location of those adults may be critically important. The adults must be in an area from which the spat can reach devastated locations; key areas appear to be Mesquite Bay and Espiritu Santo Bay. If this hypothesis is true, a significant reduction in oyster numbers or a complete loss in these areas could jeopardize recovery of San Antonio Bay oysters from natural disasters such as the 1987 flood. Further definition of the spat source for San Antonio Bay would assist managers in identifying and protecting oysters critical for these recoveries.

Other possible sources of parent stock are the isolated populations noted by TPWD personnel. Considering the large extent of the oyster community in San

Antonio Bay, under normal conditions it is likely that there were other surviving isolated populations not reported. Investigations might be warranted to document these locations for future protection of adults.

The 1986–87 flood event in the San Antonio Bay system was one of the most devastating on record. Low salinity, combined with high temperatures, was most likely responsible for the severity of the 1987 San Antonio Bay mortality. Heavy rainfall during the 5 months preceding the record June flood had already exposed the oyster community to salinities <10 ppt for 4 months, and thus they were likely in a stressed condition. The June flood lowered salinities to <5 ppt while water temperatures were >27° C. The July 1987 and August 1987 inflows were also unusually large. This combination of prolonged low salinity and high temperature resulted in severe oyster mortality.

Other authors have noted similar effects of temperature and salinity on Eastern oysters. Quast et al. (1988) noted that Eastern oyster tolerance of low salinity decreased with increasing temperature and that they can survive extended periods of low salinity if temperatures are also low. Paparo and Dean (1984) concluded that oysters acclimated to low (5 ppt) or intermediate (15 ppt) salinity are stressed more by a decrease to very low salinities than are those acclimated to a higher salinity (30 ppt). Presumably, this is due to their theory that oysters acclimated to a low salinity are already in a stressed condition.

The long-term monitoring program begun by TPWD in 1986 was critical to the conduct of this study. Without a continuous program like this in place, it is unlikely that effects of flooding, subsequent recovery, and the spawner-recruit relationship could have been quantified. The typical approach to determining the effects of an unpredictable event like a major flood relies heavily on short-term sampling that begins with the flood and ends shortly thereafter. Long-term monitoring, if adequately designed, requires no additional sampling effort to detect those same changes.

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