TRENDS TOWARD DECREASING SIZE OF BROWN SHRIMP, *PENAEUS AZTECUS*, AND WHITE SHRIMP, *PENAEUS SETIFERUS*, IN REPORTED ANNUAL CATCHES FROM TEXAS AND LOUISIANA[1]

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ABSTRACT

An exponential model adequately characterized the size composition (expressed as a regression of transformed cumulative percentage of weight on size category) of reported annual catches of brown and white shrimp in Texas and Louisiana from 1959 to 1976. Louisiana catches contained considerably greater proportions of small shrimp than did Texas catches. For both species and States, there was a significant trend toward increase in proportion of small shrimp in the catches over the period.

The size composition of a stock has long been used as a simple criterion for assessing the status of a fishery (Henderson 1972; Ricker 1975). Decreasing average size of individuals can be an indication of increasing mortality (usually equated with increased fishing mortality) or decreasing growth (usually attributed to overcrowding). This paper develops a new and simple approach to assessing size composition of catches, and uses it to detect differences and trends in size composition of brown shrimp, *Penaeus aztecus*, and white shrimp, *P. setiferus*, catches in Texas and Louisiana.

We chose to compare Texas and Louisiana shrimp fisheries because 1) they are regulated by substantially different laws (Christmas and Etzold 1977), resulting in different size distributions of shrimp harvested within the two States, and 2) they are adjacent States which together produced the bulk (75%) of the reported shrimp catch from inshore and offshore waters of the U.S. coast of the Gulf of Mexico in 1975. Inshore refers to estuarine or bay waters landward of barrier islands, and offshore refers to waters seaward of barrier islands.

Texas shrimp laws provide for licenses, limits on number and size of trawls used per boat inshore, limits on trawl mesh size, daily limits on inshore catch, and size limits on food shrimp (not on bait shrimp) during the fall (15 August-15 December) open season inshore and during all open seasons offshore. No size limits are imposed on food shrimp during the spring (15 May-15 July) open season inshore. All offshore areas are closed to shrimping from 1 June to 15 July, and offshore areas within 7 fathoms are closed from 16 December to 1 February. No nighttime shrimping is allowed inshore. These laws lead to a fishing strategy emphasizing the harvest of larger shrimp offshore, with considerable restriction of harvest of smaller shrimp inshore.

Louisiana shrimp laws provide for licenses, limits on number and size of trawls used per boat inshore, limits on trawl mesh size, and size limits during the fall open season (third Monday in August to 21 December), with the exception that size limits are removed for brown shrimp after 15 November. No size limits are imposed during the spring open season (opened not later than 25 May and extending 50 days thereafter unless closure is warranted to protect young white shrimp). Nighttime shrimping with "butterfly nets" (wing nets) is allowed inshore. These laws encourage a fishing strategy emphasizing harvest of considerable quantities of small shrimp inshore as well as harvest of larger shrimp offshore.

Brown and white shrimp spend the juvenile and subadult phases of their life cycles inshore, and the adult and larval phases offshore (Caillouet and Patella 1978), thus recruitment to the fishery begins in the juvenile or subadult phases. The entire life cycle is completed within a year, therefore the shrimp crop in a given year depends upon recruitment in that year. Environmental

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factors affecting maturation and spawning of adults and survival of larvae, juveniles, and subadults apparently have pronounced influences on recruitment. While some maturation and spawning takes place year around, peaks occur in spring and fall.

The size composition of the reported annual catches of brown and white shrimp greatly affects the value of these catches. For the years 1959-75, Caillouet and Patella (1978) estimated that the ex-vessel value (expressed in dollar units based upon 1975) of reported annual catches of brown shrimp in Texas was 1.6 times greater than that in Louisiana, for a given weight of catch. For white shrimp, it was 1.2 times greater in Texas than in Louisiana. They attributed these differences in value of the catches to differences in size composition of the catches because larger shrimp command higher prices than do smaller shrimp on the market. In addition, they were impressed that the size composition of reported catches of brown and white shrimp had remained remarkably constant within each State despite wide variations in weight of the annual catch from year to year in response to fluctuations in recruitment.

DESCRIPTION OF DATA

This paper deals with combined inshore and offshore reported annual catches of brown shrimp and white shrimp from the Texas coast (statistical areas 18-21) and Mississippi River to Texas (statistical areas 13-17), representing the Texas coast and that part of the Louisiana coast west of the Mississippi River, respectively (Figure 1), and from 1959-76 (U.S. Fish and Wildlife Service 1960-69; National Marine Fisheries Service 1970-78).

The annual catches reported in the Gulf Coast Shrimp Data (U.S. Fish and Wildlife Service 1960-69; National Marine Fisheries Service 1970-78) represent only a portion of the total annual catches; those landed by United States craft at U.S. ports along the coast of the Gulf of Mexico. Portions not reported include some of the commercial landings (including those of foreign fishing craft), undersized shrimp that are discarded, and landings by domestic sport fishermen. The proportion of the total annual catch that is not reported is unknown, and we do not know what effect its inclusion would have on size composition of the annual catch. However, we believe that the reported catch represents the bulk of the total catch and that the reported catch is a reasonably good reflection of the combined effects of shrimp population characteristics (growth and natural mortality) and removals by fishing (or fishing mortality).

Size composition of the reported catches was examined in units of pounds (as reported in catch statistics) caught in eight "count" or size categories representing number of shrimp per pound, heads-off (≥68, 51-67, 41-50, 31-40, 26-30, 21-25, 15-20, and <15). These categories are approximately equivalent to the following number of shrimp per kilogram (heads-off), respectively: ≥150, 112-148, 90-110, 68-88, 57-66, 46-55, 33-44, and <33. The use of count (number per pound) as a measure of shrimp size amounts to a reciprocal transformation of the weight (W) per shrimp (in pound):

$$\text{Count} = \frac{1}{W}$$

The same would be true if count and weight per shrimp were expressed in metric units. Kutkuhn (1962) described biases associated with determination of size composition of reported shrimp catches, including those resulting from interview sampling methods, from prevailing practices of catch culling, grading or sorting, and from catch sampling practices. Because the methods used to determine size composition of catches have remained essentially unchanged from 1959 to 1976 (Farley[3]), we believe that the biases would have

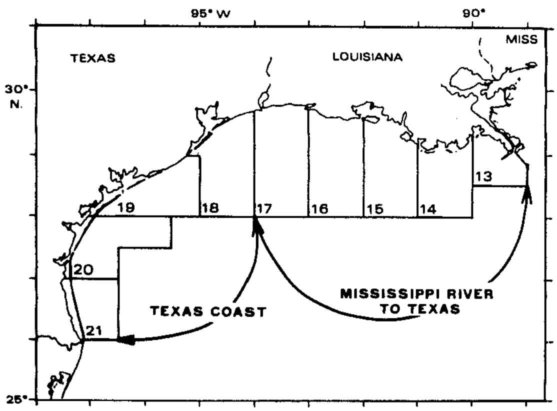

FIGURE 1.—Statistical areas used in reporting Gulf Coast Shrimp Data for Mississippi River to Texas and Texas coast.

[3]Orman Farley, National Marine Fisheries Service, NOAA, Galveston, Tex., pers. commun. December 1978.

more or less constant effects on comparisons between Texas and Louisiana and over the period from 1959 to 1976, and therefore would have only minor if any effects upon our conclusions. We further recognize that each size category may include representatives of more than one peak of recruitment, since they include catches taken over the period of 1 calendar year. Therefore, it is likely that any differences or trends in the time phasing of peak fishing activity within Texas and Louisiana within a year could contribute to the observed differences and trends in size composition of the respective catches in the two States.

ANALYTICAL METHODS

Percentage (by weight, heads-off) was determined for each size category in reported annual catches of brown and white shrimp from Texas coast and Mississippi River to Texas for each of the years from 1959 through 1976 (see Caillouet and Patella 1978). Cumulative percentage (F) for each size category was then determined for catches of both species, from Texas coast and Mississippi River to Texas, and for each year. Percentages were summed from the smallest shrimp (highest count, ≥ 68) to the largest (lowest count, <15).

An exponential model was chosen to represent the relationship between cumulative percentage, F, and size category, C, for brown and white shrimp, for Texas coast and Mississippi River to Texas, and for the years 1959-76 as follows:

$$\hat{F}_i = ae^{bC_i}$$

where F_i = cumulative percentage (by weight, heads-off) of catch in ith size category
C_i = lower limit of ith size category ($C_1 = 15, C_2 = 21, \ldots, C_7 = 68$)
i = $1, 2, \ldots, 7$
a = constant
b = exponent
e = base of natural logarithm.

The cumulative percentages, F, were transformed to natural logarithms, and the logarithmic form of the model was used to estimate parameters by least squares:

$$\ln F_i = \ln(a) + bC_i = \epsilon$$

where ϵ = residual (deviation from regression).

Thus, the logarithmic form of the model describes the relationship between transformed cumulative percentage and size category, and represents size composition of the reported annual catches. Note that this linear relationship describing size composition of the reported annual catches is achieved by transforming both the cumulative percentage to $\ln F$ and the weight per shrimp (in pound, heads-off) to count (number per pound).

Midpoints of size categories were not used because the size categories have unequal intervals, an unavoidable result of using data based on size categories developed by the shrimping industry. Upper limits of size categories were not used, because we could not determine the upper limit of the ≥ 68 category, and this category represented a significant proportion of the catches. Also, we did not use the <15 size category because we could not determine its lower limit (zero was not realistic), and this category represented a very small fraction of the catches. Apparently, total mortality (natural and fishing combined) is such that relatively small portions of the shrimp populations survive to be caught at sizes as large as <15/pound. Because lower limits of size categories were used for regression analyses, and because the <15 size category was not used in the analysis, the magnitude of the ordinate intercept, $\ln(a)$, is of no particular use. It is the slope, b (= exponent of the exponential model) that is of most interest and use as an index showing the rate of change in $\ln F$ with C. Extrapolation below 15 count is not advised, because the linear relationship does not apply beyond this point.

In order to determine whether size composition of the reported annual catches changed with time, the slopes, b, of the regressions of transformed cumulative percentage on size category were plotted against years, and straight lines were fitted to points b and x (= last two digits of each year) by least squares, for brown and white shrimp from the Texas coast and Mississippi River to Texas, 1959-76 (Figures 2, 3).

RESULTS AND DISCUSSION

Slopes, b, of the regressions of transformed cumulative percentage versus size category, all differed significantly from zero at the 99.9% level of confidence, showing that the linear fit was good (Tables 1, 2). The slopes changed with time as

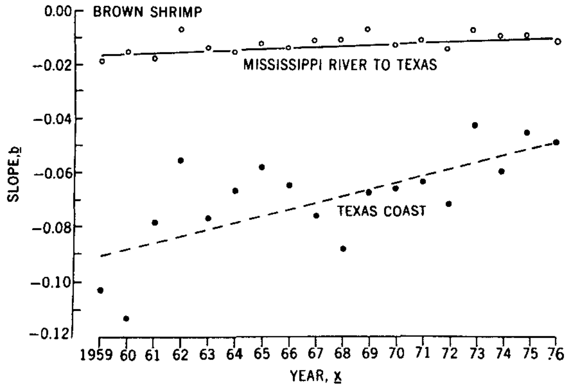

FIGURE 2.—Trends in slope (b) of regressions of transformed cumulative percentage (ln$F$) on size category (C) for brown shrimp in Mississippi River to Texas (solid line, circles) and Texas coast (dashed line, dots) 1959-76 (data from Tables 1, 2).

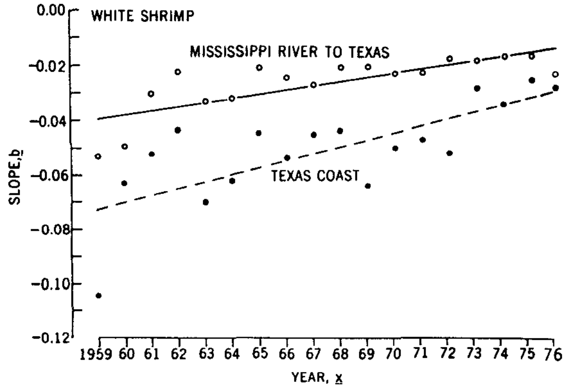

FIGURE 3.—Trends in slope (b) of regressions of transformed cumulative percentage (ln$F$) on size category (C) for white shrimp in Mississippi River to Texas (solid line, circles) and Texas coast (dashed line, dots), 1959-76 (data from Tables 1, 2).

shown by positive trends that were significantly different from zero at the 95% level of confidence (Table 3; Figures 2, 3). This change in b with time indicated that the size composition of the reported annual catches of brown and white shrimp shifted during 1959-76 toward greater proportions of shrimp of smaller size in the catches. This shift was more pronounced in Texas, but the Louisiana catches contained considerably greater proportions of small shrimp than did those of Texas. Points for 1959 and 1960 may be less reliable than those for later years because the Gulf Coast Shrimp Data reports were released for the first time in 1956, and by 1961 the data collection methods had been greatly refined. Elimination of data points for 1959 and 1960 decreased all the trends in b, and the trend for brown shrimp from Mississippi River to Texas was no longer different from zero at the 95% level of confidence (Table 3). However, elimination of points for the first 2 yr from the trends also reduced the degrees of freedom from 16 to 14 for the test of significance of trends, so the test was less sensitive in this case. Whether or not the apparent trend was real for brown shrimp from Mississippi River to Texas could be determined by examination of data for years beyond 1976, as they become available.

TABLE 1.—Linear regressions of transformed cumulative percentage (ln F) on size category (C) for brown and white shrimp, Mississippi River to Texas (based on U.S. Fish and Wildlife Service 1960-69; National Marine Fisheries Service 1970-78).[1]

	Brown shrimp			White shrimp		
Year	ln(a)	b	r^2	ln(a)	b	r^2
1959	4.881	−0.0196	0.962	5.508	−0.0537	0.992
1960	4.767	−0.0154	0.978	5.468	−0.0496	0.988
1961	4.842	−0.0180	0.976	5.097	−0.0301	0.990
1962	4.696	−0.0077	0.994	5.005	−0.0222	0.968
1963	4.823	−0.0144	0.980	5.273	−0.0336	0.960
1964	4.817	−0.0156	0.927	5.101	−0.0318	0.998
1965	4.749	−0.0126	0.992	4.849	−0.0206	0.996
1966	4.795	−0.0144	0.988	5.003	−0.0248	0.952
1967	4.786	−0.0119	0.992	4.928	−0.0273	0.994
1968	4.730	−0.0117	0.982	4.849	−0.0207	0.986
1969	4.654	−0.0079	0.947	4.922	−0.0207	0.998
1970	4.747	−0.0135	0.988	4.884	−0.0227	0.986
1971	4.746	−0.0118	0.994	4.936	−0.0230	0.996
1972	4.795	−0.0152	0.992	4.818	−0.0179	0.992
1973	4.601	−0.0080	0.872	4.852	−0.0184	0.996
1974	4.657	−0.0101	0.910	4.767	−0.0171	0.980
1975	4.657	−0.0105	0.910	4.760	−0.0165	0.968
1976	4.712	−0.0112	0.964	4.889	−0.0232	0.980

[1]F = Cumulative percentage of weight caught in each of seven size categories; C = lower limit of each of seven size categories; all b's were significantly different from zero at the 99.9% level of confidence; r^2 = coefficient of determination.

TABLE 2.—Linear regressions of transformed cumulative percentage (ln F) on size category (C) for brown and white shrimp, Texas coast (based on U.S. Fish and Wildlife Service 1960-69; National Marine Fisheries Service 1970-78.).[1]

	Brown shrimp			White shrimp		
Year	ln(a)	b	r^2	ln(a)	b	r^2
1959	6.651	−0.1039	0.965	6.848	−0.1042	0.895
1960	6.961	−0.1140	0.957	6.008	−0.0635	0.899
1961	6.069	−0.0790	0.972	5.448	−0.0521	0.990
1962	5.525	−0.0558	0.977	5.369	−0.0436	0.993
1963	5.936	−0.0771	0.986	5.875	−0.0704	0.990
1964	5.743	−0.0669	0.995	5.697	−0.0625	0.994
1965	5.626	−0.0588	0.991	5.268	−0.0449	0.998
1966	5.692	−0.0655	0.984	5.478	−0.0541	0.995
1967	6.016	−0.0764	0.980	5.171	−0.0455	0.991
1968	6.420	−0.0883	0.964	5.462	−0.0440	0.946
1969	5.901	−0.0680	0.969	5.808	−0.0643	0.983
1970	5.737	−0.0661	0.986	5.412	−0.0502	0.994
1971	5.784	−0.0629	0.973	5.302	−0.0476	0.998
1972	6.010	−0.0722	0.979	5.470	−0.0522	0.992
1973	5.427	−0.0437	0.978	5.140	−0.0283	0.976
1974	5.690	−0.0603	0.989	5.023	−0.0343	0.984
1975	5.432	−0.0460	0.991	4.995	−0.0259	0.992
1976	5.457	−0.0478	0.990	5.032	−0.0278	0.995

[1]F = Cumulative percentage of weight caught in each of seven size categories; C = lower limit of each of seven size categories; all b's were significantly different from zero at the 99.9% level of confidence; r^2 = coefficient of determination.

TABLE 3.—Trends in slopes (b) of regressions of transformed cumulative percentage ($\ln F$) on size category (C) for brown and white shrimp, Mississippi River to Texas and Texas coast, 1959-76 vs. 1961-76 (based on data from Tables 1, 2; Figures 2, 3).

	Brown shrimp				White shrimp			
	Mississippi R.-Texas		Texas coast		Mississippi R.-Texas		Texas coast	
Item	1959-1976	1961-1976	1959-1976	1961-1976	1959-1976	1961-1976	1959-1976	1961-1976
Trend[1]	0.00036*	0.00026	0.00244*	0.00141	0.00148*	0.00077*	0.00255*	0.00183*
Trend coefficient of determination	0.332	0.172	0.492	0.289	0.574	0.496	0.542	0.448

[1]Equals slope of the regression of b on x where x is the last two digits of each year.
*The change in slope (b) per year was significantly different from zero at the 95% level of confidence.

There was a positive correlation (r = 0.702) between the slopes of regressions of transformed cumulative percentage on size category for brown and white shrimp from Mississippi River to Texas in 1959-76, that was significantly different from zero at the 99% level of confidence. The same was true (r = 0.742) for brown and white shrimp from the Texas coast. This indicated that the direction of the shift in size composition of reported catches within a given year was usually in the same direction for both species in a given State (Tables 1, 2).

For a given weight of reported annual catch, the ex-vessel value of shrimp harvested in Louisiana is considerably less than that in Texas (Caillouet and Patella 1978), and this is largely a function of the size composition of the respective catches in the two States. Our analysis cannot distinguish whether the observed differences and trends in size composition of the reported catches are due to differences and trends in fishing mortality, natural mortality, or growth, but we suggest that the predominant causes of the observed differences and trends are differences and trends in fishing mortality. There is no evidence to indicate that separate shrimp stocks exist in these two States, or that natural mortality or growth differ between the two States (see Christmas and Etzold 1977). On the other hand the number and size of shrimp fishing craft and other indices of fishing effort are different in the two States and have increased over time (Christmas and Etzold 1977; Caillouet and Patella 1978). Also, differences and trends in time phasing of peak fishing activity in Texas and Louisiana within a year could have contributed to the differences and trends in size composition reported herein. Regardless of the cause or causes, continued shifts in size composition toward greater proportions of smaller shrimp in the catches can be expected to weaken the ex-vessel value of the catches.

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