

Trends in Ex-vessel Value and Size Composition of Annual Landings of Brown, Pink, and White Shrimp From the Gulf and South Atlantic Coasts of the United States

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Introduction

Caillouet and Patella (1978) and Caillouet et al. (1979, 1980) compared the commercial shrimp fisheries of the states bordering the Gulf of Mexico, using size composition of reported annual catches of brown shrimp, *Penaeus aztecus*, pink shrimp, *P. duorarum*, and white shrimp, *P. setiferus*, and its relationship to ex-vessel value of these catches. They compared these fisheries primarily because 1) the fisheries were regulated by different laws (Christmas and Etzold, 1977) resulting in different size compositions of shrimp harvested within the Gulf states, and 2) the ex-vessel value of the catches was influenced by the size composition of the catches. They showed that the average annual ex-vessel value per pound (expressed in dollar units based on the year 1975) for reported annual catches of shrimp in Texas was greater than that

ABSTRACT—Exponential models were used to characterize 1) ex-vessel value per shrimp by size category in reported annual landings, 2) size composition of reported annual landings (expressed as cumulative weight of landings by size category), and 3) ex-vessel value composition of reported annual landings (expressed as cumulative value of the landings by size category) for brown shrimp, *Penaeus aztecus*, pink shrimp, *P. duorarum*, and white shrimp, *P. setiferus*, from the Gulf and south Atlantic coasts of the United States for 1961-77. Exponents of the models were used to describe fluctuations and trends in ex-vessel value per shrimp, in size composition, and in ex-vessel value composition of the annual landings of the three species on the two coasts.

for other Gulf states from 1959 to 1975. They attributed differences in average annual ex-vessel value per pound to differences in size composition of the shrimp catches among the states. Because large shrimp commanded higher prices than did small shrimp on the market, and because a greater proportion of the reported catch from Texas was made up of large shrimp, the ex-vessel value of a given weight of catch was higher in Texas than in other Gulf states.

Size composition of a stock has long been used as a simple criterion for assessing status of a fishery (Henderson, 1972; Ricker, 1975). A decrease in average size of individuals can indicate an increase in mortality (usually equated with an increase in fishing mortality) or a decrease in growth (usually attributed to overcrowding). Socioeconomic factors also influence the size composition of the catches and landings in a fishery. Such factors affect strategies of fishing, culling of the catch, and marketing of the landings by fishermen. In most cases, socioeconomic forces override biological considerations in determining what the optimum harvesting strategies should be.

Caillouet et al. (1980) developed a simple exponential model to describe and characterize the size composition (expressed as cumulative percentage of

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weight by size category) of reported annual catches of shrimp. Using a logarithmic transformation, they simplified the model by converting it to a straight line equation, the slope of which was used to investigate fluctuations and trends in size composition of brown and white shrimp catches in Texas and Louisiana from 1959 to 1976. They detected trends toward decreasing size of brown and white shrimp in the reported annual catches in the two Gulf states.

Our paper uses exponential models to characterize 1) ex-vessel value per shrimp by size category, 2) size composition, and 3) ex-vessel value composition of the reported annual landings of brown, pink, and white shrimp from the Gulf and south Atlantic coasts of the United States from 1961 to 1977. Exponents of these models are used to investigate fluctuations and trends. Finally, simulations are conducted to predict the results of further changes in ex-vessel value by size category and in size composition of the landings.

Description of Data

The coastal shrimp fisheries of the Gulf have been described by Christmas and Etzold (1977), and those of the south Atlantic have been described by Calder et al. (1974).

Annual weight and value of landings for 1961-69 were obtained from the U.S. Fish and Wildlife Service (1962-71), those for 1970-76 were obtained from the National Marine Fisheries Service (1971-78), and unpublished data on annual weight and value of landings for 1977 were obtained from Richard L. Schween.¹ The weight of reported annual landings was expressed in pounds (heads-off, referring to shrimp with heads removed), and the ex-vessel value in dollars, by year (1961-77), coastal area (Gulf and south Atlantic coasts), species (brown, pink, and white shrimp), and size category, commonly referred to as "count" (number

¹Richard L. Schween, Supervisory Computer Specialist, Resource Statistics Division, National Marine Fisheries Service, NOAA, Washington, D.C., pers. commun. January 1979.

of shrimp per pound, heads-off, including <15, 15-20, 21-25, 26-30, 31-40, 41-50, 51-67, ≥ 68 , and "pieces"). English rather than metric units were used throughout our paper because they have been used historically, and information would be lost in their conversion. Count, as an expression of shrimp size, is equivalent to a reciprocal transformation of the weight (W , in pounds, heads-off) per shrimp as follows: count = $1/W$. Landings used herein represented catches landed by domestic

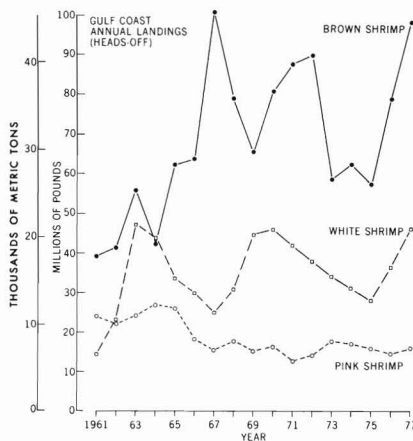


Figure 1.—Reported annual landings of brown, pink, and white shrimp from the Gulf coast, 1961-77 (based on U.S. Fish and Wildlife Service (1962-71), National Marine Fisheries Service (1971-78), and unpublished data).

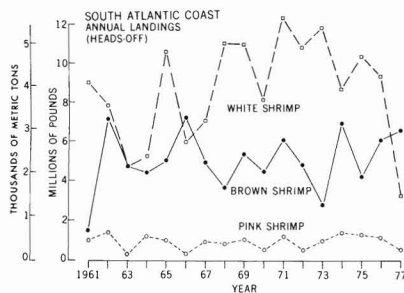


Figure 2.—Reported annual landings of brown, pink, and white shrimp from the south Atlantic coast, 1961-77 (based on U.S. Fish and Wildlife Service (1962-71), National Marine Fisheries Service (1971-78), and unpublished data).

commercial fishermen at ports in each coastal area, for shrimping trips completed within each year along the respective coast, and reported by the National Marine Fisheries Service or its predecessor, the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service.

Analyses and Results

Landings

Landings were dominated by brown and white shrimp (Fig. 1, 2). Brown shrimp landings usually exceeded those of white shrimp on the Gulf coast, and white shrimp landings usually exceeded those of brown shrimp on the south Atlantic coast. Pink shrimp landings were the lowest on both coasts. In 1977, the weight of the combined landings of brown, pink, and white shrimp was 15 times greater on the Gulf coast than on the south Atlantic coast. This characteristically large difference in weight of landings on the two coasts is one of the major differences between these two fisheries.

The analyses described herein were conducted for each species and both coastal areas separately to allow comparisons among species and coastal areas.

Annual Average Ex-vessel Value per Shrimp by Size Category

To characterize the relationship between annual average ex-vessel value per shrimp and size category with a simple linear function, we first divided dollars by pounds in each of seven (15-20, 21-25, 26-30, 31-40, 41-50, 51-67, and ≥ 68) of the nine size categories for each year. Next, we divided annual average ex-vessel value per pound in each of the seven size categories by the lower limit, C , of the respective size categories (15, 21, 26, 31, 41, 51, and 68) to obtain annual average ex-vessel value per shrimp, V , in each of the seven size categories for each year. Since lower limits of size categories were used as divisors, the calculated value per shrimp was the highest that could be obtained from the

data for each size category. The following exponential model described the relationship between V_i and C_i for each year:

$$\widehat{V}_i = ae^{bC_i}$$

where V_i = annual average ex-vessel value per shrimp for the i th size category,

C_i = lower limit of the i th size category ($C_1 = 15$, $C_2 = 21, \dots, C_7 = 68$),

$i = 1, 2, \dots, 7$, and

e = base of natural logarithms.

A logarithmic transformation of the exponential model provided a simple linear function used to estimate parameters a and b of the model (Tables 1-3) by least squares.

Lower limits rather than midpoints of the seven size categories were used in the model because the size categories had unequal intervals. Upper limits of the size categories were not used because an upper limit could not be determined for the " ≥ 68 " category. A lower limit could not be determined for the "<15" category (zero was not realistic); also this category represented only a small fraction (≤ 5.2 percent) of the annual landings of any of the three species on the Gulf coast, and it was devoid of landings for all three species in most years on the south Atlantic coast. Therefore, the model did not encompass the value per shrimp in the <15 size category. The category "pieces" was disregarded, because it was assumed to represent all size categories in proportion to their representation in the landings. The magnitude of the constant, a , was influenced by our use of lower limits (rather than midpoints or upper limits) of size categories in fitting the model. The slope, b , of the logarithmic form of the exponential model was of greater interest as a simple index characterizing the relationship between value per shrimp and shrimp size. No lines were fitted for pink shrimp from the south Atlantic coast for 1965-72, because more than one of the seven size categories were devoid of landings in those years.

Table 1.—Relationship between transformed ex-vessel value per shrimp, $\ln V$, and size category, C , for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77¹ (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)².

Year	Gulf coast			South Atlantic coast		
	a^1	b^1	Coefficient of determination r^2	a	b	Coefficient of determination r^2
1961	0.08010	-0.04491	0.977	0.08362	-0.04817	0.980
1962	0.11052	-0.04543	0.983	0.10168	-0.04556	0.981
1963	0.09904	-0.05298	0.988	0.07862	-0.04694	0.983
1964	0.09333	-0.04912	0.981	0.08404	-0.04678	0.985
1965	0.09643	-0.04762	0.982	0.08980	-0.04505	0.968
1966	0.12840	-0.04760	0.995	0.10584	-0.04168	0.972
1967	0.11541	-0.05137	0.978	0.08113	-0.04053	0.925
1968	0.16649	-0.05571	0.987	0.13461	-0.04844	0.978
1969	0.16835	-0.05295	0.994	0.13657	-0.04517	0.973
1970	0.15058	-0.05362	0.986	0.12891	-0.04681	0.969
1971	0.23915	-0.05851	0.992	0.19464	-0.05200	0.983
1972	0.23580	-0.05396	0.989	0.21576	-0.05199	0.984
1973	0.29406	-0.04895	0.995	0.27135	-0.04712	0.983
1974	0.27701	-0.05854	0.973	0.24749	-0.05649	0.949
1975	0.42151	-0.05666	0.998	0.31128	-0.04780	0.981
1976	0.53778	-0.05815	0.993	0.42919	-0.05298	0.972
1977	0.45506	-0.05636	0.986	0.39352	-0.05186	0.979

¹Based upon least squares fit of $\ln V$ on C , where V = annual average ex-vessel value (dollars) per shrimp in each of seven size categories, C = lower limit of each of the seven size categories, $\ln(a)$ = intercept, and b = slope; all slopes, b , were significantly different from zero at the 99 percent level of confidence.

²Data for 1977 were obtained from NMFS computer printouts.

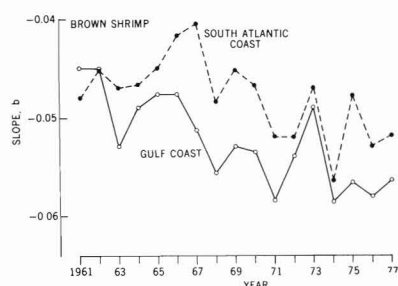


Figure 3.—Variations in slope, b , of the least squares fit of transformed ex-vessel value per shrimp, $\ln V$, on size category, C , for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 1).

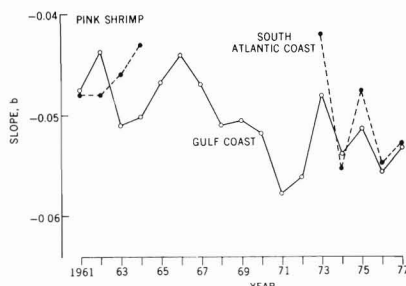


Figure 4.—Variations in slope, b , of the least squares fit of transformed ex-vessel value per shrimp, $\ln V$, on size category, C , for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 2).

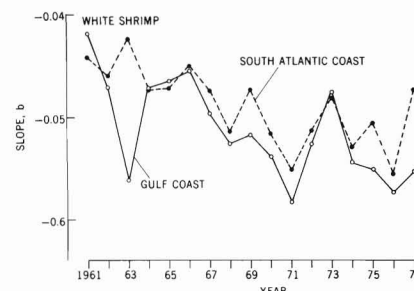


Figure 5.—Variations in slope, b , of the least squares fit of transformed ex-vessel value per shrimp, $\ln V$, on size category, C , for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 3).

There were significant² downward trends in the slopes, b , of the relationships between $\ln V$ and C for brown, pink, and white shrimp on the Gulf coast and for brown and white shrimp on the south Atlantic coast (Table 4;

²Refers throughout this paper to the 95 percent level of confidence, unless otherwise noted.

Fig. 3-5). These trends indicated that the differences in value per shrimp among shrimp in different size categories increased with time; in these cases, the value per shrimp increased more rapidly for larger shrimp than for smaller shrimp during 1961-77. No trend in b could be determined for pink shrimp on the south Atlantic coast, because of missing data for 1965-72

(Fig. 4), but annual levels of b for all species on both coasts paralleled each other to a great extent (Fig. 3-5). Such parallels would be expected if the economic forces affecting the relationship between value per shrimp and shrimp size in the landings in a given year had similar impacts on all three species on both coasts. The annual levels of b were higher (lower absolute

Table 2.—Relationship between transformed ex-vessel value per shrimp, $\ln V$, and size category, C , for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77¹ (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)².

Year	Gulf coast			South Atlantic coast		
	a^1	b^1	Coefficient of determination r^2	a	b	Coefficient of determination r^2
1961	0.08431	-0.04755	0.987	0.08437	-0.04802	0.983
1962	0.10268	-0.04383	0.993	0.10230	-0.04807	0.981
1963	0.11110	-0.05101	0.990	0.07692	-0.04607	0.985
1964	0.09868	-0.05026	0.996	0.07613	-0.04310	0.973
1965	0.09773	-0.04679	0.991	— ³	— ³	— ³
1966	0.10721	-0.04416	0.985	—	—	—
1967	0.12162	-0.04700	0.987	—	—	—
1968	0.14171	-0.05105	0.983	—	—	—
1969	0.16013	-0.05054	0.987	—	—	—
1970	0.16135	-0.05186	0.992	—	—	—
1971	0.21356	-0.05776	0.997	—	—	—
1972	0.26013	-0.05619	0.992	—	—	—
1973	0.24597	-0.04810	0.993	0.20882	-0.04207	0.961
1974	0.26840	-0.05392	0.960	0.31936	-0.05532	0.923
1975	0.30870	-0.05135	0.996	0.30546	-0.04761	0.944
1976	0.50282	-0.05566	0.995	0.52915	-0.05480	0.985
1977	0.43713	-0.05325	0.979	0.42047	-0.05282	0.963

¹Based upon least squares fit of $\ln V$ on C , where V = annual average ex-vessel value (dollars) per shrimp in each of seven size categories, C = lower limit of each of the seven size categories, $\ln(a)$ = intercept, and b = slope; all slopes, b , were significantly different from zero at the 99 percent level of confidence.

²Data for 1977 were obtained from NMFS computer printouts.

³Data were lacking in more than one size category for 1965-72, so no lines were fitted.

Table 3.—Relationship between transformed ex-vessel value per shrimp, lnV, and size category, C, for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77¹ (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)².

Year	Gulf coast			South Atlantic coast		
	a ¹	b ¹	Coefficient of determination r ²	a	b	Coefficient of determination r ²
1961	0.08076	-0.04188	0.980	0.08741	-0.04421	0.973
1962	0.11439	-0.04709	0.984	0.11206	-0.04604	0.981
1963	0.10147	-0.05625	0.979	0.07303	-0.04237	0.976
1964	0.08797	-0.04716	0.970	0.09903	-0.04730	0.983
1965	0.09337	-0.04650	0.979	0.09852	-0.04724	0.988
1966	0.11814	-0.04557	0.984	0.11282	-0.04497	0.996
1967	0.12345	-0.04975	0.976	0.11387	-0.04755	0.977
1968	0.16171	-0.05269	0.979	0.15609	-0.05148	0.989
1969	0.16180	-0.05182	0.990	0.15174	-0.04745	0.991
1970	0.15420	-0.05401	0.987	0.14960	-0.05169	0.985
1971	0.24147	-0.05834	0.989	0.23077	-0.05525	0.987
1972	0.24393	-0.05277	0.986	0.22812	-0.05136	0.977
1973	0.29471	-0.04763	0.993	0.29985	-0.04812	0.995
1974	0.26805	-0.05459	0.972	0.24536	-0.05297	0.978
1975	0.40884	-0.05523	0.997	0.37067	-0.05063	0.992
1976	0.53710	-0.05737	0.990	0.50905	-0.05560	0.987
1977	0.43628	-0.05540	0.983	0.33953	-0.04748	0.983

¹Based upon least squares fit of lnV on C, where V = annual average ex-vessel value (dollars) per shrimp in each of seven size categories, C = lower limit of each of the seven size categories, ln(a) = intercept, and b = slope; all slopes, b, were significantly different from zero at the 99 percent level of confidence.

²Data for 1977 were obtained from NMFS computer printouts.

level) in most years for all species on the south Atlantic coast than on the Gulf coast, indicating that the differences in value per shrimp among the various size categories were greater on the Gulf coast than on the south Atlantic coast (Tables 1-3; Fig. 3-5).

Annual Cumulative Landings by Size Category

Size composition of reported annual landings also was characterized with a simple linear function. First we calculated the cumulative weight, P, of landings in each of the same seven size categories for each year. Landings were cumulated starting with the size category of smallest shrimp (highest count, ≥68) and continuing toward the size category of largest shrimp (lowest count, 15-20).

The following exponential model described the relationship between P_i and C_i for each year for the Gulf coast:

$$\widehat{P}_i = ce^{dC_i}$$

where P_i = cumulative weight of landings in the ith size category.

A logarithmic transformation converted the exponential model to a sim-

ple linear function used to estimate parameters c and d of the model (Tables 5-7) by least squares.

Lower limits of the size categories were used for the same reasons described in the preceding section. Pieces and the <15 category were excluded from the calculations. The magnitude of the constant, c, was influenced by use of lower limits of size categories in fitting the model and by exclusion of pieces from the calculations. The slope, d, of the logarithmic form of the exponential model was of greater inter-

Table 4.—Trends in slopes, b, of the least squares fit of transformed ex-vessel value per shrimp, lnV, on size category, C, for reported annual landings of brown, pink, and white shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Tables 1-3)¹.

	Brown shrimp	Pink shrimp	White shrimp
Gulf coast trend ²			
Intercept	-0.0041	-0.0147	-0.0082
Slope	-0.0007*	-0.0005*	-0.0006*
Coefficient of determination	0.606	0.427	0.444
South Atlantic coast trend ²			
Intercept	-0.0149	— ³	-0.0135
Slope	-0.0005*	—	-0.0005*
Coefficient of determination	0.352	—	0.476

¹Asterisk indicates that the slope of the trend (i.e., the change in slope, b, per year) was significantly different from zero at the 95 percent level of confidence.

²Represents the least squares fit of b on x, where x is the last two digits of each year, 1961-77.

³No trend was determined because data were lacking for 1965-72 (see Table 2).

Table 5.—Relationship between transformed cumulative weight of landings, lnP, and size category, C, for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77¹ (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)².

Year	Gulf coast			South Atlantic coast		
	c ¹	d ¹	Coefficient of determination r ²	c	d	Coefficient of determination r ²
1961	72,282,311	-0.04128	0.982	10,477,598	-0.08261	0.992
1962	59,236,591	-0.02753	0.992	40,287,830	-0.07094	0.980
1963	93,356,868	-0.03484	0.984	49,421,692	-0.09644	0.975
1964	72,145,105	-0.03649	0.998	58,712,312	-0.11128	0.990
1965	101,422,955	-0.03130	0.997	84,442,383	-0.10712	0.932
1966	94,011,719	-0.02844	0.982	81,749,479	-0.09798	0.962
1967	166,870,730	-0.03190	0.982	792,870,133	-0.18494	0.856
1968	123,211,137	-0.02775	0.991	42,934,661	-0.10861	0.992
1969	91,699,731	-0.02343	0.997	74,904,161	-0.10873	0.971
1970	120,245,976	-0.02832	0.992	42,153,151	-0.09897	0.994
1971	132,019,474	-0.02663	0.986	42,744,026	-0.08134	0.976
1972	146,015,012	-0.03073	0.991	34,649,366	-0.07966	0.968
1973	80,892,365	-0.02313	0.996	20,989,860	-0.07895	0.948
1974	88,903,316	-0.02643	0.977	38,875,703	-0.06507	0.932
1975	85,276,545	-0.02647	0.998	30,462,287	-0.07573	0.943
1976	107,116,759	-0.02108	0.990	35,400,624	-0.06767	0.927
1977	147,774,792	-0.02425	0.994	70,115,890	-0.09753	0.973

¹Based upon least squares fit of lnP on C, where P = cumulative weight (pounds, heads-off) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, ln(c) = intercept, and d = slope; all slopes, d, were significantly different from zero at the 99 percent level of confidence.

²Data for 1977 were obtained from NMFS computer printouts.

est as a simple index characterizing the size composition of the landings.

The model was modified for the south Atlantic coast because of generally small percentages of landings of any of the three species in the 15-20 size category (≤7.9 percent in all years except 1963 in which it was 14.6 percent for pink shrimp only). Both the 15-20 size category as well as the <15 size category were excluded in fitting the model for all species and years. No lines were fitted for pink shrimp for 1967-70, because no landings of pink

Table 6.—Relationship between transformed cumulative weight of landings, $\ln P$, and size category, C , for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77¹ (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)².

Year	Gulf coast			South Atlantic coast		
	c^1	d^1	Coefficient of determination r^2	c	d	Coefficient of determination r^2
1961	54,114,893	-0.04692	0.981	3,068,072	-0.04078	0.939
1962	69,840,177	-0.05926	0.979	3,524,397	-0.03975	0.957
1963	58,694,114	-0.04535	0.981	1,078,509	-0.05276	0.972
1964	71,589,574	-0.04847	0.969	9,149,959	-0.07824	0.905
1965	74,243,441	-0.05204	0.972	31,636,434	-0.11857	0.842
1966	47,649,372	-0.04669	0.959	14,266,005	-0.12550	0.708
1967	47,784,888	-0.05516	0.945	— ³	— ³	— ³
1968	59,293,485	-0.05938	0.953	—	—	—
1969	48,201,948	-0.05472	0.927	—	—	—
1970	40,405,643	-0.04372	0.947	—	—	—
1971	38,623,444	-0.05379	0.924	4,251,915	-0.04470	0.839
1972	51,004,274	-0.06260	0.915	1,862,295	-0.04814	0.907
1973	61,719,470	-0.05720	0.890	3,299,099	-0.04517	0.896
1974	58,886,946	-0.05842	0.909	3,863,484	-0.03556	0.681
1975	49,471,139	-0.05307	0.895	3,154,498	-0.03136	0.739
1976	46,045,473	-0.05435	0.897	3,428,385	-0.03827	0.785
1977	41,649,920	-0.04337	0.878	1,302,219	-0.04080	0.928

¹Based upon least squares fit of $\ln P$ on C , where P = cumulative weight (pounds, heads-off) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, $\ln(c)$ = intercept, and d = slope; all slopes, d , were significantly different from zero at the 99 percent level of confidence.

²Data for 1977 were obtained from NMFS computer printouts.

³There were no reported landings in the ≥ 68 size category in 1967-70, so no lines were fitted.

Table 7.—Relationship between transformed cumulative weight of landings, $\ln P$, and size category, C , for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77¹ (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)².

Year	Gulf coast			South Atlantic coast		
	c^1	d^1	Coefficient of determination r^2	c	d	Coefficient of determination r^2
1961	26,391,961	-0.03704	0.996	32,298,133	-0.06215	0.994
1962	37,142,410	-0.02682	0.986	33,364,399	-0.06085	0.987
1963	90,903,585	-0.03438	0.978	26,589,315	-0.07628	0.992
1964	78,314,239	-0.03671	0.999	25,593,014	-0.07193	0.993
1965	48,293,136	-0.02684	0.999	86,645,878	-0.08607	0.967
1966	45,934,177	-0.02764	0.978	22,302,738	-0.06073	0.998
1967	36,665,983	-0.03188	0.993	109,842,711	-0.11446	0.982
1968	47,651,754	-0.02885	0.996	144,705,326	-0.10421	0.953
1969	69,087,889	-0.02816	0.996	66,246,289	-0.07255	0.972
1970	67,461,660	-0.02916	0.989	53,691,218	-0.08399	0.996
1971	61,811,501	-0.02715	0.997	53,366,833	-0.06183	0.975
1972	51,489,064	-0.02412	0.993	44,105,718	-0.05776	0.972
1973	48,858,553	-0.02242	0.994	49,275,620	-0.05817	0.963
1974	39,538,285	-0.02173	0.985	37,743,733	-0.06375	0.993
1975	35,271,647	-0.01973	0.985	41,466,648	-0.05900	0.977
1976	50,649,504	-0.02457	0.989	29,014,318	-0.04839	0.978
1977	64,385,564	-0.02235	0.993	28,550,928	-0.11271	0.998

¹Based upon least squares fit of $\ln P$ on C , where P = cumulative weight (pounds, heads-off) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, $\ln(c)$ = intercept, and d = slope; all slopes, d , were significantly different from zero at the 99 percent level of confidence.

²Data for 1977 were obtained from NMFS computer printouts.

shrimp were reported in the ≥ 68 category in those years. Thus, the least squares fit of $\ln P$ on C for south Atlantic coast landings was based upon only six size categories instead of seven. Because estimates of parameters c and d for all species on the south Atlantic coast were based on fewer data points than those for the Gulf coast, comparisons between south Atlantic and Gulf coasts with regard to parameters c and d were not strictly valid. Elimination of the 15-20 size category from the model for the south Atlantic coast probably decreased (increased the absolute value) the slopes, d , for landings from the south Atlantic coast. The lack of landings in the <15 size category and the paucity of landings in the 15-20 size category on the south Atlantic coast could have reflected limited availability to the fishery of shrimp in these size categories (e.g., they may have been present only on untrawlable grounds) or lower abundance of larger shrimp due to higher total mortality or attainment of smaller maximum sizes in colder waters (McCoy, 1972).

Time trends in d are shown in Figures 6-8. There were significant upward trends in d (Table 8; Fig. 6, 8) for

brown and white shrimp landings from the Gulf coast, indicating that the size of shrimp in the reported landings decreased from 1961 to 1977. Annual values of d for pink shrimp on the Gulf coast were lower than those for brown and white shrimp (Tables 5-7; Fig. 6-8), but there was no significant trend in d with time for pink shrimp (Table 8; Fig. 7). Annual levels of d for brown, pink, and white shrimp fluctuated widely on the south Atlantic coast (Tables 5-7; Fig. 6-8). In addition, the low level of d for brown and white shrimp landings on the south Atlantic coast in 1967 may have indicated low recruitment in that year.

Annual Cumulative Ex-vessel Value of Landings by Size Category

Ex-vessel value composition of the reported annual landings also was characterized with a simple linear function. First we calculated ex-vessel value of landings in each of the seven size categories for each year. Ex-vessel value of landings was cumulated to obtain D_i , starting with the size category of smallest shrimp and continuing toward the size category of largest shrimp.

Table 8.—Trends in slopes, d , of the least squares fit of transformed cumulative weight of landings, $\ln P$, on size category, C , for reported annual landings of brown, pink, and white shrimp from the Gulf coast, 1961-77 (based on data from Tables 5-7)¹.

Gulf coast trend ²	Brown shrimp	Pink shrimp	White shrimp
Intercept	-0.0826	-0.0385	-0.0840
Slope	0.0008*	-0.0002	0.0008*
Coefficient of determination	0.574	0.030	0.658

¹Asterisk indicates that the slope of the trend (i.e., the change in slope, d , per year) was significantly different from zero at the 95 percent level of confidence. No trend was determined for brown, pink, and white shrimp from the south Atlantic coast because d fluctuated widely (see Tables 5-7; Fig. 6-8).

²Represents the least squares fit of d on x , where x is the last two digits of each year, 1961-77.

The following exponential model described the relationship between D_i and C_i for each year for the Gulf coast:

$$\widehat{D}_i = g e^{h C_i}$$

where D_i = cumulative ex-vessel value of landings in the i th size category.

A logarithmic transformation converted the exponential model to a simple linear function used to estimate parameters g and h of the model (Tables 9-11) by least squares.

Table 9.—Relationship between transformed cumulative ex-vessel value of landings, $\ln D$, and size category, C , for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77¹ (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)².

Year	Gulf coast			South Atlantic coast		
	g^1	h^1	Coefficient of determination r^2	g	h	Coefficient of determination r^2
1961	47,080,525	-0.05345	0.979	7,715,640	-0.09857	0.993
1962	46,878,514	-0.03855	0.986	36,185,896	-0.08446	0.985
1963	62,076,000	-0.05310	0.984	35,530,783	-0.11173	0.979
1964	47,277,261	-0.05059	0.998	49,161,433	-0.12788	0.991
1965	68,438,083	-0.04422	0.997	63,686,935	-0.11870	0.945
1966	89,200,749	-0.04378	0.985	84,558,994	-0.10908	0.973
1967	125,051,974	-0.04780	0.983	531,843,589	-0.19137	0.873
1968	113,289,834	-0.04555	0.988	55,344,619	-0.12619	0.995
1969	87,904,363	-0.03958	0.994	92,952,577	-0.12188	0.978
1970	108,192,218	-0.04522	0.984	48,831,199	-0.11367	0.996
1971	168,095,025	-0.04774	0.989	66,072,950	-0.09933	0.981
1972	213,387,432	-0.04864	0.988	60,647,562	-0.09803	0.974
1973	152,426,032	-0.03737	0.995	47,656,996	-0.09306	0.961
1974	125,700,167	-0.04586	0.965	46,414,850	-0.07837	0.947
1975	212,822,704	-0.04785	0.997	74,525,358	-0.08940	0.957
1976	276,970,068	-0.04057	0.988	96,970,755	-0.08276	0.947
1977	337,761,303	-0.04110	0.992	227,206,533	-0.11582	0.980

¹Based upon least squares fit of $\ln D$ on C , where D = cumulative ex-vessel value (dollars) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, $\ln(g)$ = intercept, and h = slope; all slopes, h , were significantly different from zero at the 99 percent level of confidence.
²Data for 1977 were obtained from NMFS computer printouts.

Table 10.—Relationship between transformed cumulative ex-vessel value of landings, $\ln D$, and size category, C , for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77¹ (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)².

Year	Gulf coast			South Atlantic coast		
	g^1	h^1	Coefficient of determination r^2	g	h	Coefficient of determination r^2
1961	38,125,732	-0.06251	0.979	1,694,317	-0.05198	0.950
1962	67,180,259	-0.07244	0.978	2,386,599	-0.05133	0.976
1963	48,048,429	-0.06214	0.983	670,273	-0.06557	0.976
1964	56,497,107	-0.06592	0.966	5,800,995	-0.08810	0.929
1965	60,146,872	-0.06612	0.972	21,207,384	-0.13162	0.839
1966	41,546,756	-0.05760	0.966	11,513,260	-0.13647	0.720
1967	45,853,404	-0.06826	0.955	—	— ³	— ³
1968	61,801,612	-0.07538	0.968	—	—	—
1969	55,026,751	-0.06969	0.944	—	—	—
1970	44,129,983	-0.05965	0.962	—	—	—
1971	55,028,401	-0.07531	0.938	4,076,992	-0.05217	0.857
1972	90,826,350	-0.08261	0.939	2,102,820	-0.05944	0.921
1973	117,200,887	-0.07131	0.916	4,786,404	-0.05066	0.905
1974	95,299,965	-0.07356	0.951	3,495,825	-0.03870	0.690
1975	115,555,328	-0.07002	0.901	4,298,557	-0.03466	0.755
1976	152,164,084	-0.07334	0.925	8,053,844	-0.04959	0.793
1977	102,679,187	-0.05706	0.921	2,751,014	-0.05192	0.959

¹Based upon least squares fit of $\ln D$ on C , where D = cumulative ex-vessel value (dollars) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, $\ln(g)$ = intercept, and h = slope; all slopes, h , were significantly different from zero at the 99 percent level of confidence, except those for the south Atlantic coast for the years 1965, 1966, 1974, 1975, and 1976, which were significantly different from zero at the 95 percent level of confidence.
²Data for 1977 were obtained from NMFS computer printouts.
³There were no reported landings in the ≥ 68 size in the years 1967-70, so no lines were fitted.

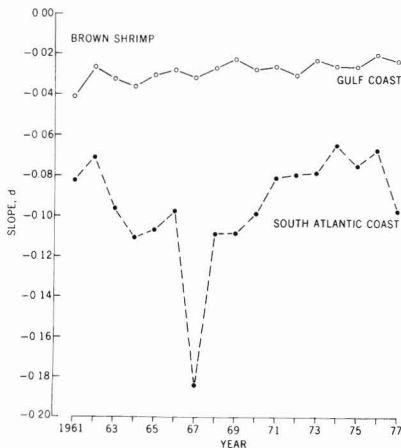


Figure 6.—Variations in slope, d , of the least squares fit of transformed cumulative weight of landings, $\ln P$, on size category, C , for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 5).

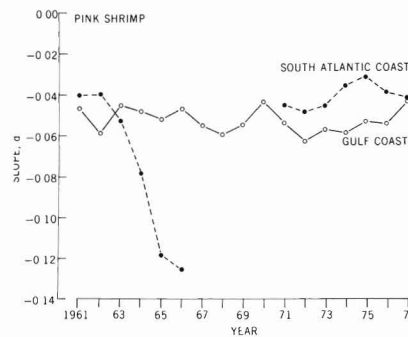


Figure 7.—Variations in slope, d , of the least squares fit of transformed cumulative weight of landings, $\ln P$, on size category, C , for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 6).

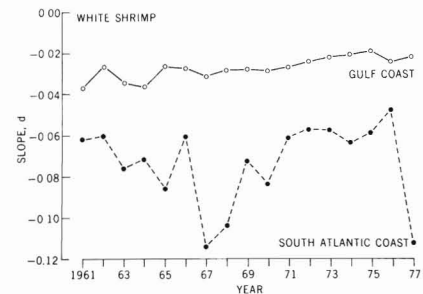


Figure 8.—Variations in slope, d , of the least squares fit of transformed cumulative weight of landings, $\ln P$, on size category, C , for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 7).

We used lower limits of the size categories as in the preceding sections and excluded pieces and the <15 size category. The magnitude of the constant g was influenced by use of lower limits of size categories in fitting the

model and by exclusion of pieces. The slope, h , of the logarithmic form of the exponential model was of greater interest as a simple index characterizing the ex-vessel value composition of the landings.

The model was modified for the south Atlantic coast, as in the preceding section, to make the analyses comparable with those for size composition of the landings (Tables 5-7; Fig. 6-8). Neither the 15-20 size category nor the

<15 size category were included in fitting the model for all species and years. No lines were fitted for pink shrimp for 1967-70. Thus, the least squares fit of $\ln D$ on C for south Atlantic coast landings was based upon only six size categories instead of seven. Because estimates of parameters g and h for all species on the south Atlantic coast were based on fewer data points than those for the Gulf coast, comparisons between south Atlantic and Gulf coasts with regard to parameters g and h were not strictly valid. Elimination of the 15-20 size category from the model for the south Atlantic coast probably decreased the slopes, g , for ex-vessel value of landings.

There were no significant trends in h with time for brown, pink, and white shrimp from the Gulf coast, but annual levels of h for pink shrimp on the Gulf coast were lower than those for brown and white shrimp (Tables 9-11; Fig. 9-11). Annual levels of h for brown, pink, and white shrimp fluctuated widely on the south Atlantic coast. For this reason, no trend lines were fitted by least squares for the south Atlantic coast. The low level of h for brown and white shrimp landings on the south Atlantic coast in 1967 reflected the unusual size composition of the landings in that year.

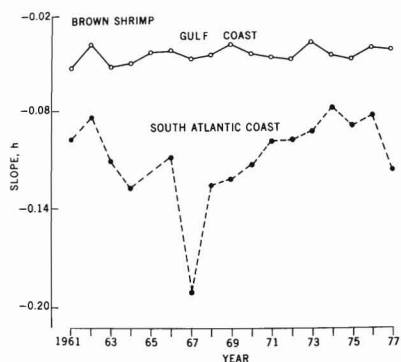


Figure 9.—Variations in slope, h , of the least squares fit of transformed cumulative ex-vessel value of landings, $\ln D$, on size category, C , for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 9).

Simulations

The models described above provided an opportunity for simulating the results of predictable changes in parameters. Our predictions were based upon the assumption that the observed trends would continue; therefore, we confined them to the Gulf coast landings, which far exceeded those of the south Atlantic coast and which showed greater stability in size composition apart

from significant trends (Tables 5-8; Fig. 6-8).

Though the Gulf coast landings of brown, pink, and white shrimp exhibited significant trends in b (Table 4; Fig. 3-5) and those of brown and white shrimp exhibited significant trends in d (Table 8; Fig. 6-8), there were no significant trends in h (Tables 9-11; Fig. 9-11). The greater increase in ex-vessel value of larger shrimp as compared with that for smaller shrimp

Table 11.—Relationship between transformed cumulative ex-vessel value of landings, $\ln D$, and size category, C , for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77¹ (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)².

Year	Gulf coast			South Atlantic coast		
	g^1	h^1	Coefficient of determination r^2	g	h	Coefficient of determination r^2
1961	17,728,428	-0.04636	0.998	25,397,467	-0.7477	0.992
1962	27,391,683	-0.03754	0.996	31,865,357	-0.07449	0.993
1963	50,210,765	-0.05136	0.991	18,208,335	-0.08751	0.995
1964	49,753,929	-0.04905	0.998	22,481,650	-0.08737	0.996
1965	30,516,559	-0.03800	0.997	77,685,563	-0.10172	0.973
1966	36,838,351	-0.03767	0.990	24,958,375	-0.07646	0.998
1967	30,708,806	-0.04659	0.986	116,815,929	-0.13054	0.986
1968	45,121,527	-0.04386	0.993	202,627,525	-0.12376	0.963
1969	69,455,721	-0.04388	0.994	89,364,136	-0.08820	0.975
1970	63,852,737	-0.04721	0.983	70,426,488	-0.10357	0.998
1971	80,572,665	-0.04800	0.996	88,673,354	-0.08186	0.978
1972	71,845,605	-0.03980	0.986	71,083,088	-0.07339	0.985
1973	90,556,090	-0.03424	0.994	126,244,366	-0.07417	0.965
1974	54,060,265	-0.03703	0.966	68,411,398	-0.08182	0.997
1975	74,140,315	-0.03743	0.977	125,361,234	-0.07678	0.984
1976	142,696,421	-0.04389	0.982	97,558,231	-0.06779	0.989
1977	141,109,960	-0.03838	0.984	99,794,138	-0.13064	0.999

¹Based upon least squares fit of $\ln D$ on C , where D = cumulative ex-vessel value (dollars) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, $\ln(g)$ = intercept, and h = slope; all slopes, h , were significantly different from zero at the 99 percent level of confidence.

²Data for 1977 were obtained from NMFS computer printouts.

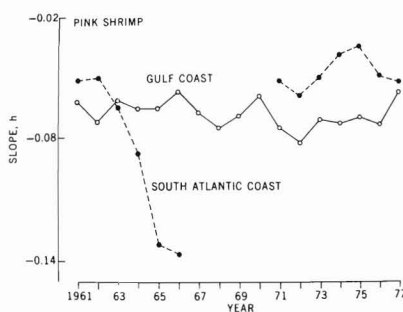


Figure 10.—Variations in slope, h , of the least squares fit of transformed cumulative ex-vessel value of landings, $\ln D$, on size category, C , for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 10).

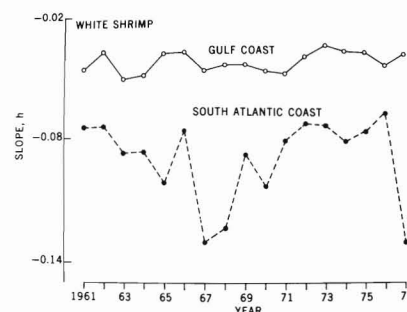


Figure 11.—Variations in slope, h , of the least squares fit of transformed cumulative ex-vessel value of landings, $\ln D$, on size category, C , for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 11).

apparently compensated the decrease in size of shrimp in the landings, because the ex-vessel value composition of the landings remained unchanged apart from year to year fluctuations. Based upon these findings, we would expect the observed trends to continue and the ex-vessel value composition of the Gulf landings to remain stable for a few more years.

We also conducted simulations to estimate what the ex-vessel value per pound of past annual landings of shrimp of each species would have been for various levels of b , to explore the possible consequences of reversing the past trends toward decreasing size of shrimp in the landings. Because there was a significant inverse relationship between $\ln(a)$ and b , as shown by least squares analysis (Table 12), we were able to estimate a for a range of levels of b , to generate parameters for the model,

$$\widehat{V}_i = ae^{bC_i}$$

We then calculated the corresponding ex-vessel value per pound by size category from the simulated V_i . We used the ex-vessel value per pound obtained for the 15-20 size category as a minimum ex-vessel value per pound for the <15 size category. This provided a conservative estimate of the ex-vessel value per pound for the <15 size category. We then multiplied ex-vessel

value per pound in each size category by the observed pounds in each size category for 1961-77. The resulting values were summed over size categories to simulate annual ex-vessel value of shrimp landings for each year. The simulated annual ex-vessel value was then divided by the annual pounds landed (Fig. 1) to obtain simulated annual average ex-vessel value per pound. Simulated annual average ex-vessel value per pound was plotted against d (Fig. 12-14) for each species and year, and straight lines were fitted by least squares (Table 13). It was obvious that an increase in size of shrimp in the landings, as indicated by a decrease in d , coupled with a decrease in b , would result in a dramatic increase in the annual average ex-vessel value per pound for shrimp landings from the Gulf coast (Fig. 12-14). It was also obvious that changes in b produced greater changes in simulated annual average ex-vessel value per pound than

equivalent changes in d . Thus the price spread among different size categories had a greater influence than changes in size composition on simulated annual average ex-vessel value per pound. Over the range in d , the change in annual average ex-vessel value per pound was slight at the higher levels of b . As b decreased, there was a greater change in annual average ex-vessel value per pound over the range in d . Because total landings also depend upon recruitment each year (Christmas and Etzold, 1977), the simulated annual ex-vessel value per pound can be used

Table 12.—Least squares fit of $\ln(a)$ on b for reported annual landings of brown, pink, and white shrimp from the Gulf coast 1961-77 (based on data from Tables 1-3).

Gulf coast	Brown shrimp	Pink shrimp	White shrimp
Intercept	-6.8591	-6.5868	-6.0833
Slope	-98.069*	-95.480*	-84.875*
Coefficient of determination	0.551	0.483	0.454

*Asterisk indicates that the slope was significantly different from zero at the 95 percent level of confidence.

Table 13.—Least squares fit of simulated annual average ex-vessel value per pound on d for brown, pink, and white shrimp from the Gulf coast, 1961-77 (based on data from Fig. 1 and Tables 1-3, 5-7, 12)¹.

b^2	Brown shrimp	Pink shrimp	White shrimp
Intercept	0.3238	0.4516	0.4183
-0.04 Slope	-2.571*	-1.028*	-3.100*
Coefficient of determination	0.964	0.361	0.923
Intercept	0.5390	0.7741	0.6405
-0.05 Slope	-7.643*	-3.236*	-7.202*
Coefficient of determination	0.944	0.342	0.774
Intercept	0.9269	1.3480	1.0262
-0.06 Slope	-19.336*	-8.378*	-14.792*
Coefficient of determination	0.918	0.332	0.646
Intercept	1.6450	2.3781	1.7129
-0.07 Slope	-45.648*	-20.038*	-28.716*
Coefficient of determination	0.892	0.330	0.540

¹Asterisk indicates that the slope was significantly different from zero at the 95 percent level of confidence.

²The levels of b chosen for the simulation encompass as well as extend the observed range (see Tables 1-3).

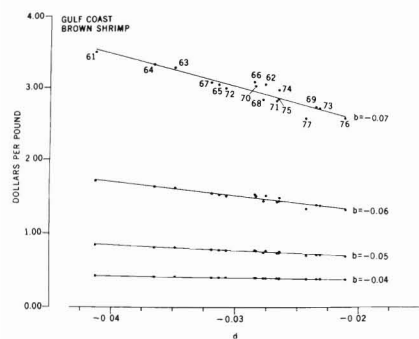


Figure 12.—Simulated annual average ex-vessel value (dollars) per pound (heads-off) of brown shrimp from the Gulf coast at various levels of b over the range of d (based on data from Fig. 1 and Tables 1, 5, 12).

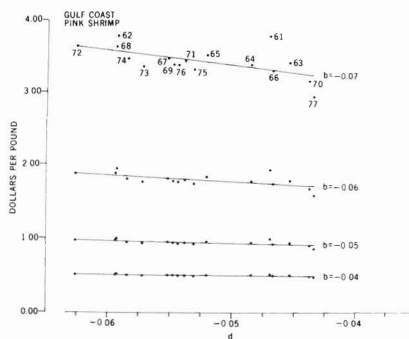


Figure 13.—Simulated annual average ex-vessel value (dollars) per pound (heads-off) of pink shrimp from the Gulf coast at various levels of b over the range of d (based on data from Fig. 1 and Tables 2, 6, 12).

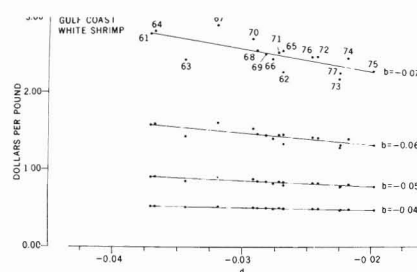


Figure 14.—Simulated annual average ex-vessel value (dollars) per pound (heads-off) of white shrimp from the Gulf coast at various levels of b over the range of d (based on data from Fig. 1 and Tables 3, 7, 12).

as a multiplier for determining annual ex-vessel value for a given weight of landings of a given size composition and for various levels of b .

There was no significant correlation between $\ln(c)$ and d (Tables 5-7), indicating that size composition of the landings was not the major factor affecting the weight of the annual landings. Such a lack of correlation would be expected if another factor (e.g., recruitment) played a larger role in determining variations in weight of shrimp landed in a given year.

Discussion

The extent to which the inclusion of unreported catches would change our results and conclusions cannot be determined. Because reported annual landings of shrimp were not equivalent to the total annual catches of shrimp, the size and ex-vessel value composition of these landings were not necessarily identical to the size and ex-vessel value composition of the total annual catches of a given species in a given coastal area and year. Unknown portions of the total annual catches were not reported; e.g., catches by foreign fishing craft, shrimp discarded because they did not meet minimum size limits or for other reasons, landings by recreational fishermen, and landings sold directly to the consumer. The proportion of the total annual catch not reported as landings was unknown.

There was a significant decrease in size of brown and white shrimp in the landings from the Gulf coast during 1961-77. Fishing effort has increased substantially on the Gulf coast (Christmas and Etzold, 1977; Caillouet and Patella, 1978; Caillouet et al., 1979). Therefore, it is possible that the observed decrease in size of shrimp in the landings was an effect of increased fishing pressure. Reported landings of brown, pink, and white shrimp on the south Atlantic coast either were totally lacking in shrimp of <15 and 15-20 count or contained only small percentages of these size categories, and the size composition of the landings fluctuated widely from year to year.

The range in ex-vessel value per shrimp among the various size cate-

gories increased during 1961-77 for all three species on both coasts. Although the annual ex-vessel value of the brown, pink, and white shrimp landings on the Gulf coast increased as the landings increased, the ex-vessel value composition of the landings did not change significantly from year to year. A greater proportion of the ex-vessel value of Gulf landings of brown and white shrimp was represented by shrimp of smaller sizes, compared with the south Atlantic coast landings of the two species. A greater proportion of the ex-vessel value of Gulf landings of pink shrimp was represented by shrimp of larger sizes, compared with Gulf landings of brown and white shrimp. The ex-vessel value composition of brown, pink, and white shrimp landings on the south Atlantic coast fluctuated widely from year to year.

For the most part, small or juvenile shrimp were harvested inshore or nearshore, and larger shrimp (subadults and adults) were harvested offshore, as related to their availability inshore or offshore in different phases of their life cycle (Christmas and Etzold, 1977; Caillouet and Patella, 1978). Trends of increase in the range in ex-vessel value per shrimp among size categories probably reflected trends in supply of shrimp vs. demand for shrimp of various sizes in domestic and world markets, but differences in costs of harvesting shrimp inshore (close to ports) vs. offshore (farther from ports) as well as other factors also may have affected the ex-vessel price spread. Further investigations of costs, supply and demand relationships, and other economic factors are needed to explain the trends we observed.

Gunter and McGraw (1973) found a significant positive correlation between annual weight and ex-vessel value of combined landings of white and brown shrimp on the Gulf coast for 1902-71. In contrast, they observed no correlation between weight and ex-vessel value of combined landings of white and brown shrimp on the south Atlantic coast. They suggested that the south Atlantic coast shrimp stocks had been fished to capacity since the 1920's when production limits seemed to have been

reached. Thus, the ex-vessel value of the landings continued to increase while the weight of landings did not. Moreover, they suggested that production of Gulf shrimp would reach an upper limit in the future if fishing continued at a high level, so that Gulf landings and ex-vessel value of the landings would no longer show a correlation, assuming that ex-vessel value of the landings continued to increase.

We have characterized and described ex-vessel value per shrimp by size category, size composition, and ex-vessel value composition of the reported annual landings of brown, pink, and white shrimp on Gulf and south Atlantic coasts. Similar analyses, including additional landings statistics that become available, should be of particular use as one means of monitoring the effects of changes in shrimp fishery management that may be brought about under the Fishery Conservation and Management Act of 1976. Finally, our analyses suggest that the ex-vessel value of a given weight of landings could be greatly increased (Fig. 12-14), if the past trends toward decreasing size of shrimp in the landings could be reversed while the trends in ex-vessel value per shrimp continued. Balanced against this must be a consideration of what management actions could be used to increase the total weight and total value of annual landings.

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