Reprinted from "Bulletin of Marine Science" Volume 37, 1985, pp. 839-856, Browder: Relationship between pink shrimp production on the Tortugas Grounds and water flow patterns in the Florida Everglades. With permission from Rosenstiel School of Marine and Atmospheric Science of the University of Miami.

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RELATIONSHIP BETWEEN PINK SHRIMP PRODUCTION ON THE TORTUGAS GROUNDS AND WATER FLOW PATTERNS IN THE FLORIDA EVERGLADES

Joan A. Browder

ABSTRACT

Regression analysis indicated a relationship between landings of pink shrimp on the Tortugas grounds and freshwater runoff to the estuarine areas of Everglades National Park, as indexed by water levels in the park. A strong positive relationship between quarterly (3-month) landings and the average water level of the previous quarter was found for three quarters of the year. October through December water levels, followed by July through September water levels, may have had the greatest influence on annual landings. An inverse relationship between landings and water levels from April through June was not precluded. Information of this type is needed in order that the freshwater needs of estuarine-dependent marine organisms can be taken into account in water management planning.

Canals, levees, weirs, and other water-control structures in the Everglades basin have altered the quantity and seasonal distribution of freshwater entering the estuaries of Everglades National Park, including Florida Bay. Changes in freshwater inflow, which began at the turn of the century, may have adversely affected commercial and recreational fish and shellfish that use these estuaries as nursery grounds. Recreational fishermen and fishing guides report that fishing success in the estuaries and near-shore waters of Everglades National Park has declined in recent years (U.S. National Park Service, 1979). Spotted seatrout (*Cynoscion nebulosus*) and red drum (*Sciaenops ocellatus*) caught by recreational fishermen in the park increased in size from 1958 to 1978, suggesting that fewer small fish were being produced (Davis, 1980).

Gunter (1961) postulated that salinity gradients in estuaries protect juvenile fish and shellfish by excluding marine predators. Changes in water-flow patterns may reduce the area of suitable bottom habitat covered by water in which certain salinities or other conditions favorable to young fish and shellfish (i.e., micronutrients or food supply) exist (Browder and Moore, 1981). Concentrations of organic matter and the nutrients that stimulate primary productivity are functions of freshwater inflow that affect the food supply of young fish and shellfish. The influence of freshwater inflow on area of favorable habitat could be positive or negative, depending on the characteristics of the particular estuary and the volume of freshwater inflow. Barrett and Gillespie (1975) presented evidence that brown shrimp landings in Louisiana depend upon the amount of estuarine area experiencing salinities above 10‰ during April and May. Negative correlation between brown shrimp (*Penaeus aztecus*) production and Mississippi River flow off Louisiana was reported in the Gulf of Mexico Shrimp Fishery Management Plan (Gulf of Mexico Fishery Management Council, 1981). Both positive and negative correlations between shrimp catches and runoff were observed in various Texas bays (Texas Dept. Water Res., 1979). Positive correlations between Texas shrimp landings and rainfall have been noted (Hildebrand and Gunter, 1952; Gunter and Hildebrand, 1954).

Local rainfall and runoff from the Everglades Conservation Areas supplies Everglades National park with fresh water. A levee adjacent to U.S. Highway 41 prevents the natural flow of water from the Conservation Areas into the park

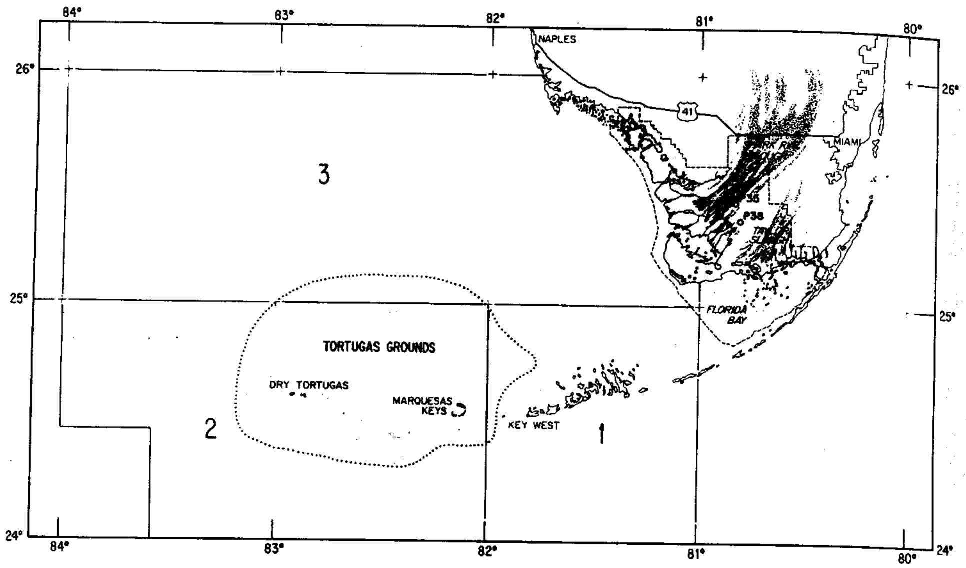


Figure 1. Everglades National Park, Tortugas fishing grounds, and statistical reporting grids 1, 2, and 3 of the National Marine Fisheries Service [modified from Tabb (1967) and Costello and Allen (1968)].

(Fig. 1). Water is released to the park from four water control structures in accordance with the water management policy of the South Florida Water Management District.

An evaluation of the effect of freshwater flow patterns on marine resources in Everglades National Park has been needed so that these resources can be adequately considered in water-management planning. Using regression analysis, I have found a statistical relationshp between landings of pink shrimp (*Penaeus duorarum*) on the Tortugas grounds and freshwater runoff to the estuaries of the park, as indexed by inland water levels.

Background and Approach

A comparison of fishery stocks before and after water management changes was not possible because no data on fishery stocks prior to water management changes were available and because the changes have occurred intermittently rather than all at one time. Data were available, however, to perform an analysis of the effect on landings of year-to-year differences in freshwater flow caused either by variation in rainfall or by water management. A strong statistical relationship between landings and water flow indicates that a change in water flow (regardless of source) could cause a change in landings.

Pink shrimp are highly dependent on the park's estuaries. After being spawned offshore, young shrimp move shoreward into Florida Bay and the fringing estuaries of the park, where they spend their juvenile stage. Then they move offshore onto the Tortugas grounds, where they are harvested by shrimp trawlers (Costello and Allen, 1966) (Fig. 1).

Pink shrimp is the one estuarine-dependent species of south Florida for which a relatively long time-series of both catch and effort data are available. Effort data need to be included in any analysis of landings in relation to environmental variation, because landings data in isolation from effort data may give an erroneous impression of the status of a stock. If effort has increased, landings can be relatively constant even when stock biomass has declined. For instance, quarterly landings of pink shrimp (heads off) changed little during the 15-year period from July 1966, through June 1980, except for seasonal variation (Fig. 2). Catch-per-unit-effort (CPUE), a more realistic index of stock size, indicates a decline in stock biomass (Fig. 3).

The data plotted in Figures 2 and 3 are for statistical reporting areas (grids) 1 and 2 of the National Marine Fisheries Service. Grids 1, 2, and 3 comprise the Tortugas shrimp grounds (Fig. 1). Data from

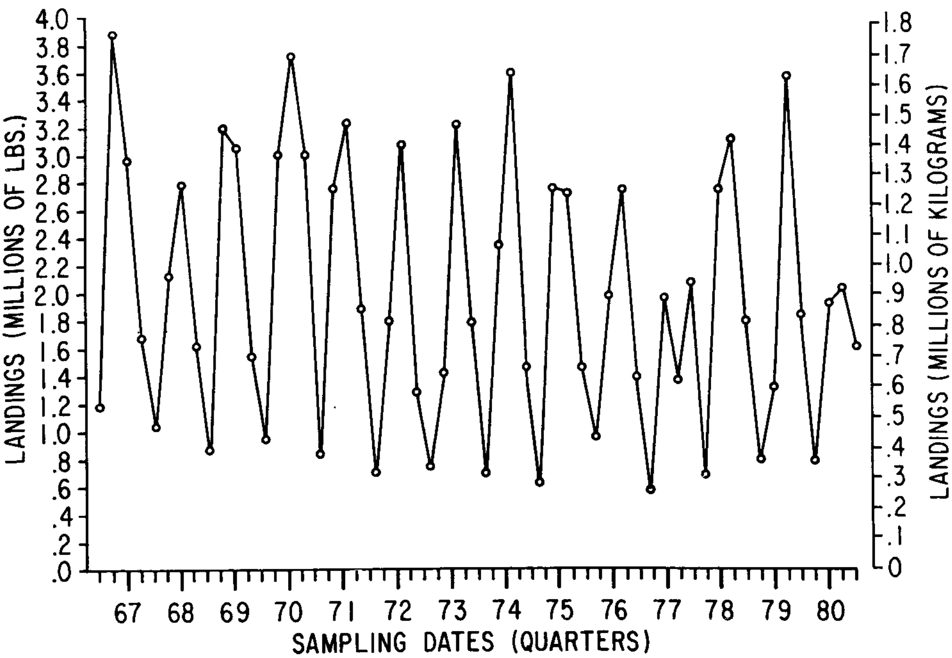


Figure 2. Quarterly landings, Tortugas pink shrimp fishery, July 1966, through June 1980 (compiled from unpublished data, National Marine Fisheries Service, Miami).

Grid 3 were not included in the analysis because a relatively large percent of the shrimp caught in Grid 3 may come from the Ten Thousand Islands rather than estuaries in the Everglades basin and also because there has been a relatively large increase in effort in Grid 3 in the past 15 years, making CPUE calculations for this area less reliable. Landings from Grids 1 and 2 make up 84% of total Tortugas landings (82% comes from Grid 2).

Standardized rather than nominal effort (Fig. 4) was used in calculating CPUE. Standardization corrected for changes in fishing power caused by changes in vessel size, engine horsepower, and fishing gear. Fifteen years of monthly standardized effort data for pink shrimp [computed from unpublished data of the Southeast Fisheries Center of the National Marine Fisheries Service, Miami, by Brunenmeister (1981)] were used in the present study. Standardized effort was correlated with nominal effort to various extents in the four quarters examined separately in this study (Table 1).

Because only Grids 1 and 2 are included and because standardized rather than nominal data were used in the calculation of CPUE, the plot of CPUE in Figure 3 may differ from that expected from Klima and Costello's (1982) discussion of the history of CPUE in the Dry Tortugas shrimp fishery.

The water flow through the Shark and Taylor Sloughs of the Everglades influences salinity distributions and the concentrations of nutrients and allochthonous organic material in all embayments along the southern and southwestern shorelines of the park, including Florida Bay (Fig. 1). Runoff to these estuaries is roughly a function of upstream water levels, which are a function of local rainfall and water releases from the South Florida Water Management District. Tabb (1967) found that approximately 86% ($\alpha = 0.01$) of the variation in the position of the freshwater isohaline in the Shark River, principal tributary of the Everglades, could be explained by variation in water levels measured the same day at Well P-35 (U.S. Geological Survey Well No. 02290830) a short distance upstream in Shark Slough (Fig. 1). Salinities in Whitewater Bay, largest of the park's embayments in the Everglades basin, are directly influenced by the Shark River. Water level data at Station P-35, measured in feet above mean sea level, have been recorded continuously and compiled as daily and monthly averages since 1953 by the U.S. Geological Survey. I used quarterly average water level at Station P-35 from July 1965, through June 1979 (Fig. 5) (U.S. Geological Survey, 1966–1980), as the index of freshwater flow to the estuaries.

In addition to landings, standardized effort, and water level, I included air temperatures (Fig. 6) and CPUEs (Fig. 3) of previous quarters as optional variables in the regression routine because their exclusion might have obscured the relationship between shrimp and fresh water. Air temperature was

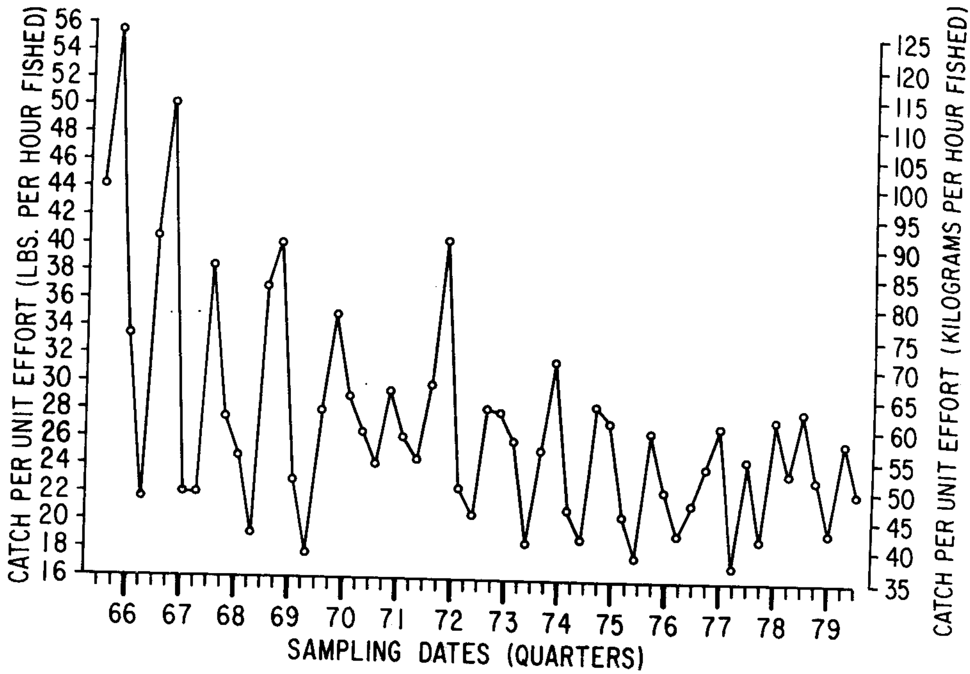


Figure 3. Quarterly average standardized catch-per-unit-effort (CPUE) in the Tortugas pink shrimp fishery, July 1965, through June 1979 [calculated from unpublished data of the National Marine Fisheries Service, Miami, by Brunenmeister (1981)].

substituted for water temperature, which could affect survival and growth in larval, postlarval, or juvenile stages. Barrett and Gillespie (1973) considered spring water temperatures important to brown shrimp production in Louisiana. CPUE was used as an index of the biomass of the spawning stock. The relationship between spawning stock and recruitment is theoretically important but often appears irrelevant in analyses, probably because it is overshadowed by other factors. Negative density-dependent effects of older cohorts, indexed by CPUE, also could be important.

Quarterly, rather than monthly or annual data, were used because the relationship between landings and effort was strongest for quarterly data. The total landings of each quarter were treated as a function of total standardized effort for the same quarter and average quarterly water levels, air temperatures, and CPUEs for each of the four preceding quarters.

The data for the analysis were compiled for the "biological year," which I defined, on the basis of the timing of peak spawning, as commencing in July and ending in June; but the quarters, as I refer to them throughout this report, are numbered according to their order in the calendar year. For instance, Quarter 3 is the first quarter of the biological year.

The general form of the regression equation tested in this analysis was:

$$L_t = a + bS_t + cS_t^2 + \sum_{z=1}^{4} d_z W_{t-z} + \sum_{z=1}^{4} e_z T_{t-z} + \sum_{z=1}^{4} f_z C_{t-z}$$

where: L_t = total quarterly landings at time t; S_t = total standardized effort at time t; W_{t-z} = average quarterly water level z quarters prior to time t; T_{t-z} = average air temperature z quarters prior to time t; $C_{t-z} = L_{t-z}/S_{t-z}$ = average CPUE z quarters prior to time t; S_{t-z} = total standardized effort z quarters prior to time t; z = the time-period lag (one, two, three, or four-quarter); and a, b, c, d, e, and f are regression coefficients.

The water level, air temperature, and CPUE from one, two, three, and four quarters earlier were tested because I did not know which previous state could affect landings (this might differ from quarter to quarter because of seasonal differences in growth rates). The number of quarters by which the effect of each variable is delayed (the "lag") is a function of (1) the timing of peak spawning and (2) the time between spawning and the appearance of new recruits on the offshore grounds. Although pink

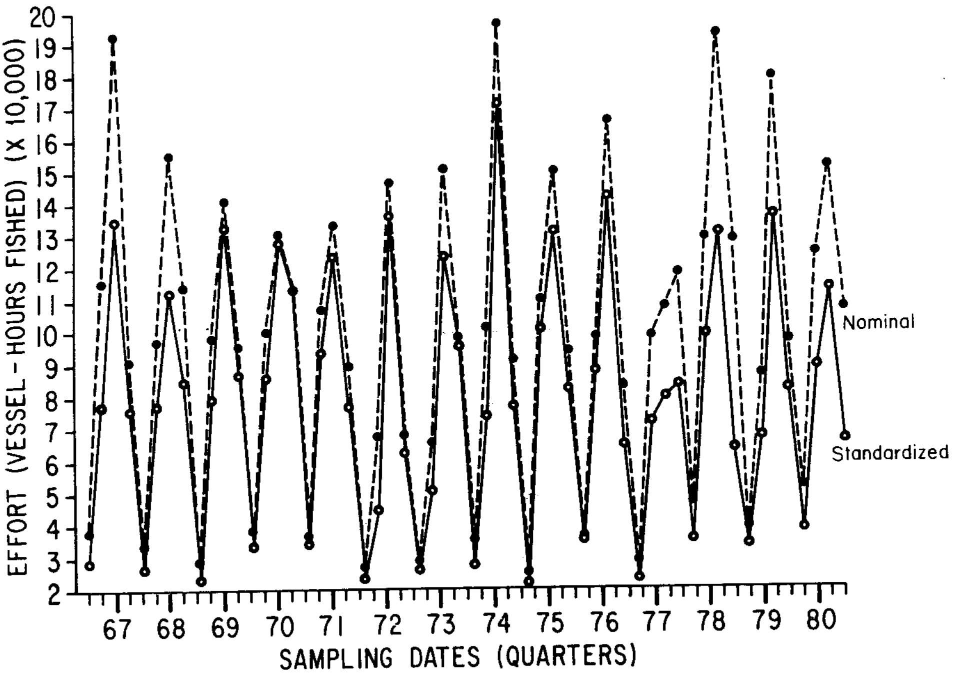


Figure 4. Quarterly total nominal and standardized effort in the Tortugas shrimp fishery (Grids 1 and 2 only), July 1966, through June 1980 [calculated from unpublished data of the National Marine Fisheries Service, Miami, by Brunenmeister (1981)].

shrimp spawn year-around, peak spawning usually occurs in early summer (Quarter 3 in this analysis), or occasionally in early fall (Munro and Jones, 1968). Pink shrimp larvae spend approximately 1 month as plankton before entering estuarine nursery grounds (Munro and Jones, 1968), where they stay from 2 to possibly more than 6 months (Costello and Allen, 1966).

The state of the stock as much as 1 year earlier (four quarters past) could be reflected in landings. Factors affecting larval growth and survival would be influential in the earlier of the previous four quarters, and factors affecting juveniles would be influential in the quarters nearest to the time of landings (Fig. 7). Thus the temperature of any one or several of the previous four quarters might influence landings, whereas freshwater runoff in more recent quarters would more likely be influential.

I performed two separate multiple regression analyses of the data. The first covered the entire data set, which consisted of data for all four quarters. The resultant regression equation estimated quarterly landings for any quarter. For the second analysis, I separated the data by quarter and developed a distinct regression equation for each quarter to distinguish seasonally differing relationships between shrimp landings and water level. Seasonal differences are important to water management planning in south Florida.

Table 1. Correlation coefficients of nominal effort and standardized effort with landings and with each other

Quarter	Nominal effort with landings	Standardized effort with landings	Nominal with standardized effort
1	0.4586	0.7567	0.7126
2	0.5368	0.7457	0.3038
3	0.2173	0.2615	0.8985
4	0.5654	0.5107	0.8679
All	0.8464	0.8698	0.9532

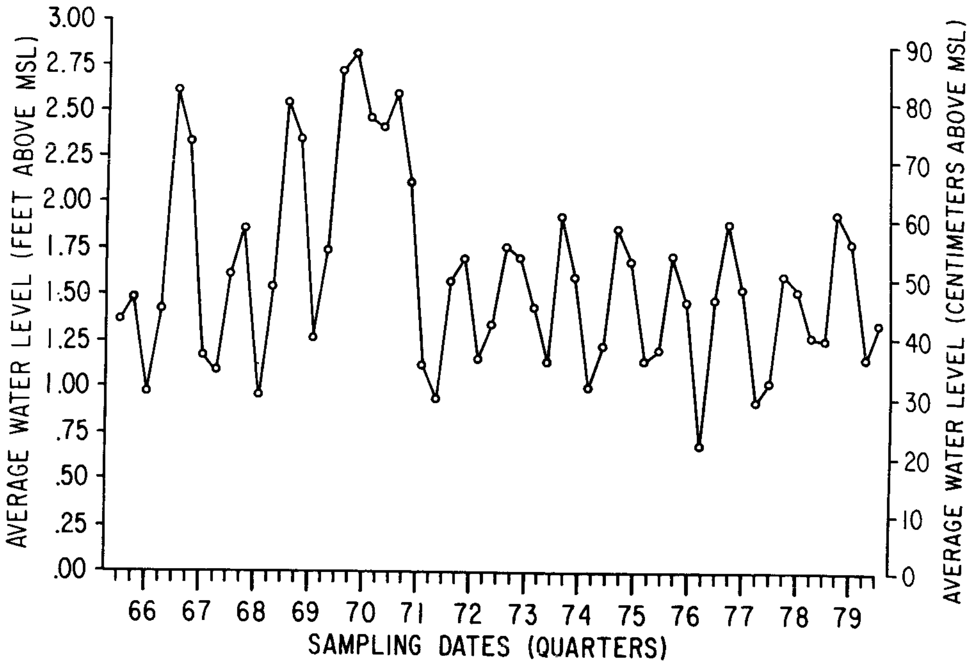


Figure 5. Quarterly average water levels, U.S.G.S. Everglades Station P-35, July 1965, through June 1979 (U.S. Geological Survey, 1966–1980).

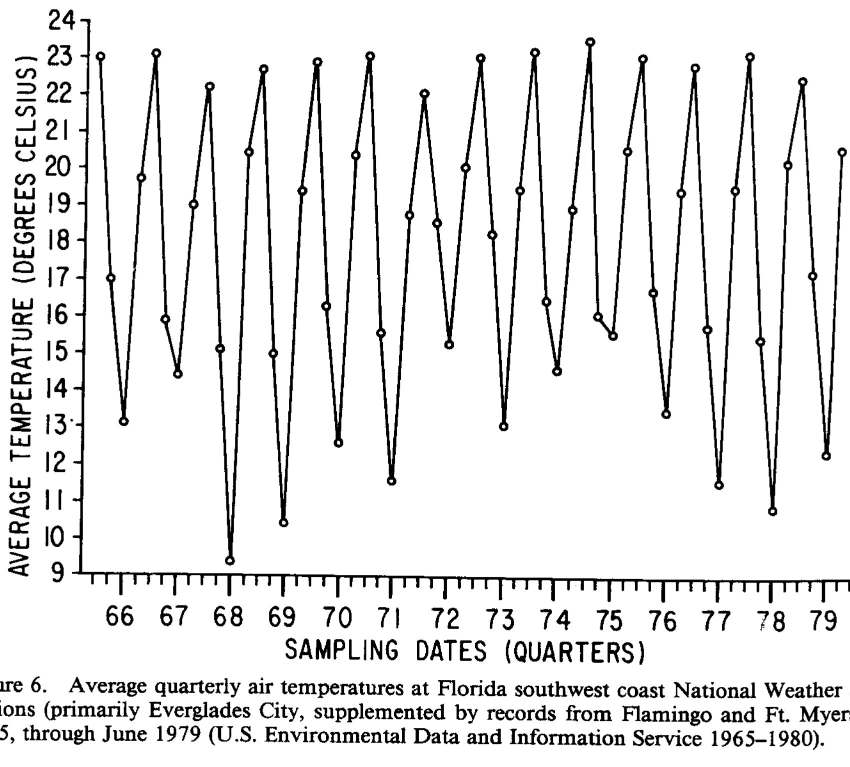


Figure 6. Average quarterly air temperatures at Florida southwest coast National Weather Service stations (primarily Everglades City, supplemented by records from Flamingo and Ft. Myers), July 1965, through June 1979 (U.S. Environmental Data and Information Service 1965–1980).

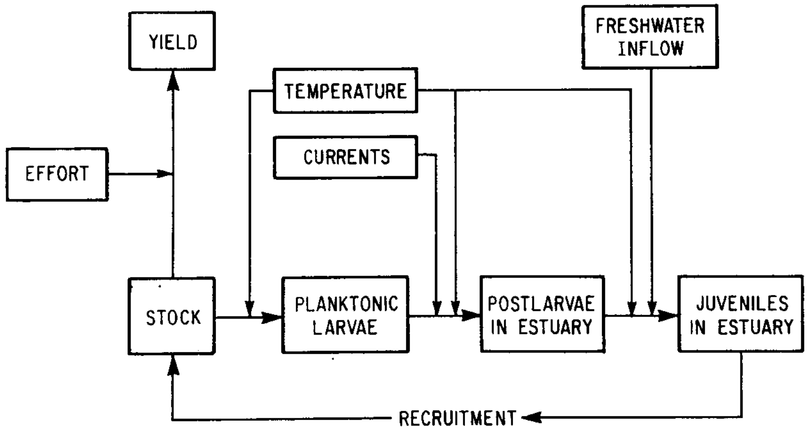


Figure 7. Possible factors influencing pink shrimp landings on the Tortugas grounds and their relative times of influence in the life cycle.

My objective was to determine the long-term rather than seasonal relationship between landings and water levels and the other variables. It was necessary, therefore, in the analysis of the data set that included all quarters, to quantify the effect of independent variables on the *non-seasonal* variation in the dependent variable. To do this, I first tested the regression of landings on the independent variables and three dummy seasonal variables (one for each quarter, minus one) (Draper and Smith, 1981). After determining that all but one of the dummy seasonal variables became insignificant in the equation after the independent variables were added (and the one significant dummy variable decreased the unexplained variation by only a small amount), I regressed landings against *only* the three dummy seasonal variables. I assumed that the resultant coefficient of determination (r^2) represented the total seasonal component of variation in the dependent variable. The difference between this r^2 and that of the regression of landings on *only* the independent variables (without the dummies) would therefore represent the minimum proportion of non-seasonal variation explained by the independent variables. Because these variables may not have described *all* of the seasonal variation, an even larger proportion of the variation explained by the independent variables may have been non-seasonal. The equation used in these computations was as follows:

$r^2_{\text{ind}} - r^2_{\text{dum}}/1 - r^2_{\text{dum}}$ = proportion of non-seasonal variation explained by the independent variables

where: r^2_{dum} = seasonal variation as proportion of total variation; $1 - r^2_{\text{dum}}$ = non-seasonal variation as proportion of total variation; $r^2_{\text{ind}} - r^2_{\text{dum}}$ = non-seasonal variation explained by independent variables, as proportion of total variation.

The SPSS multiple regression routine "forward stepwise inclusion" (Nie et al., 1975), executed on a Honeywell 6600 computer, was used to build the regression equation, utilizing various combinations of parameters. I used the adjusted r^2 (Draper and Smith, 1981) and the Student t values for the individual regression coefficients to determine the optimum cutoff point for adding variables to the equation. Variables that, when added to the equation, caused the adjusted r^2 to decrease were not used. (The adjusted r^2 is a correction in r^2 for the number of independent variables employed in the equation. This statistic can be used to compare the fit to a dependent variable of different combinations and different numbers of independent variables.) Variables with nonsignificant (0.1) regression coefficients also were eliminated from the equation.

In original executions, the regression routine was forced to solve the regression equation using effort and the square of effort and then to add the other variables in order of the amount of variation they explained. In subsequent executions, the squared effort term was excluded because its usage led to theoretically non-meaningful results (Roff and Fairbairn, 1980).

One equation applicable to every quarter (from analysis of the combined data set) and one equation specific to each quarter (from separate analyses of data sets for each quarter) were selected from a number of alternatives according to two criteria. First, the equation had to have an adjusted r^2 greater than 0.65. Second, the equation had to be theoretically reasonable (for example, an equation that included standardized effort as a negative term would be rejected). Where more than one equation met the criteria, those whose regression coefficients were significant at the lowest levels were selected.

Table 2. Results of regressions of quarterly landings from the combined quarterly data set on (A) independent variables, (B) dummy seasonal variables, and (C) independent and dummy seasonal variables (N = 56)

A. Landings (L) vs. standardized effort (S); water level, lagged one quarter (W_{t-1}); and catch-per-unit-effort, lagged four quarters (C_{t-4}).

Variable	Regression coefficient	Standardized regr. coeff.	Student's t	Sig. of t
S	9.3031	0.8235	14.09	<0.0005
W_{t-1}	6,744.79	0.2432	4.08	<0.001
C_{t-4}	22,719.3	0.1928	3.40	<0.005
Const.	−455,057			

Multiple r = 0.9387 F Stat. = 128.43
r^2 = 0.8811 df = 3,52 Av. residual = 152,382
Adjust. r^2 = 0.8742 Sig. of F < 0.001 Durbin-Watson = 2.46

B. Landings (L) vs. Quarter 2 season dummy variable (D_2), Quarter 3 seasonal dummy variable (D_3), and Quarter 4 seasonal dummy variable (D_4).

Variable	Regression coefficient	Standardized regr. coeff.	Student's t	Sig. of t
D_2	−542,590	−0.5518	6.00	<0.0005
D_3	−964,906	−0.9812	10.67	<0.0005
D_4	−258,811	−0.2632	2.86	<0.005

Multiple r = 0.8406 F Stat. = 41.74
r^2 = 0.7066 df = 3,52
Adjust. r^2 = 0.6897 Sig. of F < 0.001

C. Landings (L) vs. standardized effort (S); water level, lagged one quarter (W_{t-1}); CPUE, lagged four quarters (C_{t-4}); Quarter 2 seasonal dummy variable (D_2)*; Quarter 3 seasonal dummy variable (D_3); and Quarter 4 seasonal dummy variable (D_4)*.

Variable	Regression coefficient	Standardized regr. coeff.	Student's t	Sig. of t
C_{t-4}	22,548.1	0.1914	3.44	0.0012
W_{t-1}	6,809.58	0.2455	4.20	0.0001
D_3	−122,799	−0.1249	1.74	0.0881
S	8.2205	0.7277	9.15	<0.00009
Const.	−335,401		2.93	0.005

Multiple r = 0.9422 F Stat. = 100.83
r^2 = 0.8877 df = 3,52 Av. residual = 149,500
Adjust. r^2 = 0.8789 Sig. of F < 0.001 Durbin-Watson = 2.38

* These two seasonal dummy variables were eliminated from the equation because their regression coefficients were not statistically significant at alpha less than 0.1.
Landings (L) are in kilograms. Standardized effort (S) is in vessel-hours fished. Water level (W) is in centimeters above mean sea level. Air temperature (T) is in degrees Celsius. CPUE (C) is in kilograms per vessel-hours fished.

Regression Results

Three variables—standardized effort, water level lagged one quarter, and CPUE lagged four quarters—explained 88% of the variation in the 14 years of combined quarterly data. The three independent variables explained at least 59% of the non-seasonal variation in landings, which accounted for 29% of total variation. These percentages were calculated using the r^2s of Regression Equations A and B in Table 2.

Selected equations for each quarter explained 86%, 71%, 99+%, and 77% of the variation in landings for Quarters 1, 2, 3, and 4, respectively (Table 3). The selected equations differed each quarter, but there were some commonalities. Standardized effort was a significant variable in every equation. The water level of the preceding quarter was also significant in equations for all quarters. The other lags of water level were included in the equation for Quarter 3. One or more quarter lags of CPUE appeared in the equations for three out of four quarters. Air temperature appeared only in the equation for Quarter 3, in which three lags

Table 3. Regression coefficients and other statistical parameters of the regression equation for each quarter for all quarters combined

Quarter 1

Variable	Regression coefficient	Standardized regr. coeff.	Student's t	Sig. of t
S	13.4203	0.9347	6.72	<0.0005
W_{t-1}	14,694.5	0.6136	3.94	<0.005
C_{t-3}	72,308.0	0.3818	2.77	<0.025
C_{t-4}	−58,393.6	−0.3894	2.38	<0.025
Const.	−1,308,612			

Multiple r = 0.9260	F Stat. = 13.55	Av. residual = 128,382
r^2 = 0.8576	df = 4,9	Range in landings = 1,067,529
Adjust. r^2 = 0.7943	Sig. of F = <0.01	Durbin-Watson = 1.79

Quarter 2

Variable	Regression coefficient	Standardized regr. coeff.	Student's t	Sig. of t
S	5.5945	0.4040	1.86	0.0899
W_{t-1}	8,003.71	0.5175	2.38	0.0364
Const.	46,819.0		0.253	0.8051

Multiple r = 0.8409	F Stat. = 13.28	Av. residual = 112,491
r^2 = 0.7071	df = 3,10	Range in landings = 779,245
Adjust. r^2 = 0.6538	Sig. of F = 0.0012	Durbin-Watson = 1.37

Quarter 3

Variable	Regression coefficient	Standardized regr. coeff.	Student's t	Sig. of t
S	0.7938	0.0573	3.38	0.0776
W_{t-1}	−1,704.21	−0.2480	14.86	0.0045
W_{t-2}	−1,390.85	−0.2243	9.66	0.0106
W_{t-4}	2,005.29	0.3569	18.78	0.0028
T_{t-1}	166,072	0.7606	29.55	0.0011
T_{t-2}	−16,778.2	−0.2254	14.31	0.0048
T_{t-4}	113,428	0.3409	27.14	0.0014
C_{t-1}	−4,356.60	−0.0851	5.063	0.0369
C_{t-2}	6,955.78	0.1715	11.98	0.0069
C_{t-3}	11,942.3	0.7238	23.74	0.0018
C_{t-4}	8,237.70	0.3585	11.53	0.0074
Const.	−445,193		35.50	0.0008

Multiple r = 0.9999	F Stat. = 988.9	Av. residual = 2,646
r^2 = 0.9998	df = 11,2	Range in landings = 277,643
Adjust. r^2 = 0.9988	Sig. of F = 0.0010	Durbin-Watson = 1.71

Quarter 4

Variable	Regression coefficient	Standardized regr. coeff.	Student's t	Sig. of t
S	10.4956	0.5050	3.04	<0.01
W_{t-1}	11,261.0	0.4350	2.54	<0.025
C_{t-1}	48,839.3	0.4407	2.58	<0.025
Const.	−1,026,085			

Multiple r = 0.8775	F Stat. = 11.16	Av. residual = 178,579
r^2 = 0.7700	df = 3,10	Range in landings = 1,165,584
Adjust. r^2 = 0.7010	Sig. of F < 0.001	Durbin-Watson = 2.65

Every quarter

Variable	Regression coefficient	Standardized regr. coeff.	Student's t	Sig. of t
S	9.3031	0.8235	14.08	<0.0005
W_{t-1}	6,751.49	0.2432	4.08	<0.0005

Table 3. Continued

Every quarter				
Variable	Regression coefficient	Standardized regr. coeff.	Student's t	Sig. of t
C_{t-4}	22,719.2	0.1928	3.40	<0.005
Const.	−455,058			
Multiple r = 0.9387	F Stat. = 128.4			
r^2 = 0.8811	df = 3,52			
Adjust. r^2 = 0.8742	Sig. of F < 0.01		Av. residual = 152,382	

S is standardized effort (vessel-hours fished) at time t.
W_{t-z} is water level (centimeters above mean sea level) z quarters prior to t.
T_{t-z} is air temperature (degrees Celsius) z quarters prior to t.
C_{t-z} is catch-per-unit-effort (kilograms per vessel-hours fished) z quarters prior to t.
Landings (kilograms) is the dependent variable.

of this variable were included. Cross correlation existed between some of the independent variables in the Quarter 3 equation, indicating a possible problem with multicollinearity (Draper and Smith, 1981; Hull and Nie, 1981) in this large equation with many lags of the same variable.

The equation developed with the combined quarterly data set had two variables in common with the equations for each quarter. These were standardized effort and water level lagged one quarter. CPUE lagged four quarters appeared in the equation common to all quarters as well as in equations specific to two of the quarters.

A summary of the specific time-lagged variables in the regression equation for each quarter is given in Figure 10. The upper segment of the figure is a key relating the numbered time lags of the equation for each quarter to corresponding months of the year. Statistically significant time lags of independent variables used in the analysis (water level, temperature, and CPUE) are positioned below the key according to the quarter of landings (row) and the quarter of the time-lagged variable (column). (Months of the year corresponding to each quarter are indicated in the heading.) For example, in Quarter 1 (January–March), water level measured one quarter prior to harvest (October–December) was significant, air temperature measured four quarters prior to harvest (January–March of the previous year) was significant, and CPUE measured three and four quarters prior to harvest (April–June and January–March of previous year) was significant. Whether the relationship between landings and the lagged variable was positive or negative is indicated by the sign preceding the subscripted letters.

The regression equations were developed from data through Quarter 2 (April–June) of 1980. When more recent data [through Quarter 4 (October–December) of 1983] became available after the analysis was completed, the equations were tested by using them to estimate landings for the more recent quarters and comparing the estimates to actual landings. Unfortunately, standardized effort data were not available for most of the more recent quarters and had to be estimated on the basis of the relationship between quarterly standardized effort and nominal effort in the original data set. Landings estimated by the regression equations can be compared to actual landings in Figures 8 and 9. Estimates for each quarter are shown in Figure 8. Quarterly estimates have been summed to provide annual estimates in Figure 9. In both figures, E_Q is the estimate from an equation (or the four equations) specific to each quarter and E_A is the estimate from the equation common to all quarters. Annual estimates are for the biological year, July through June.

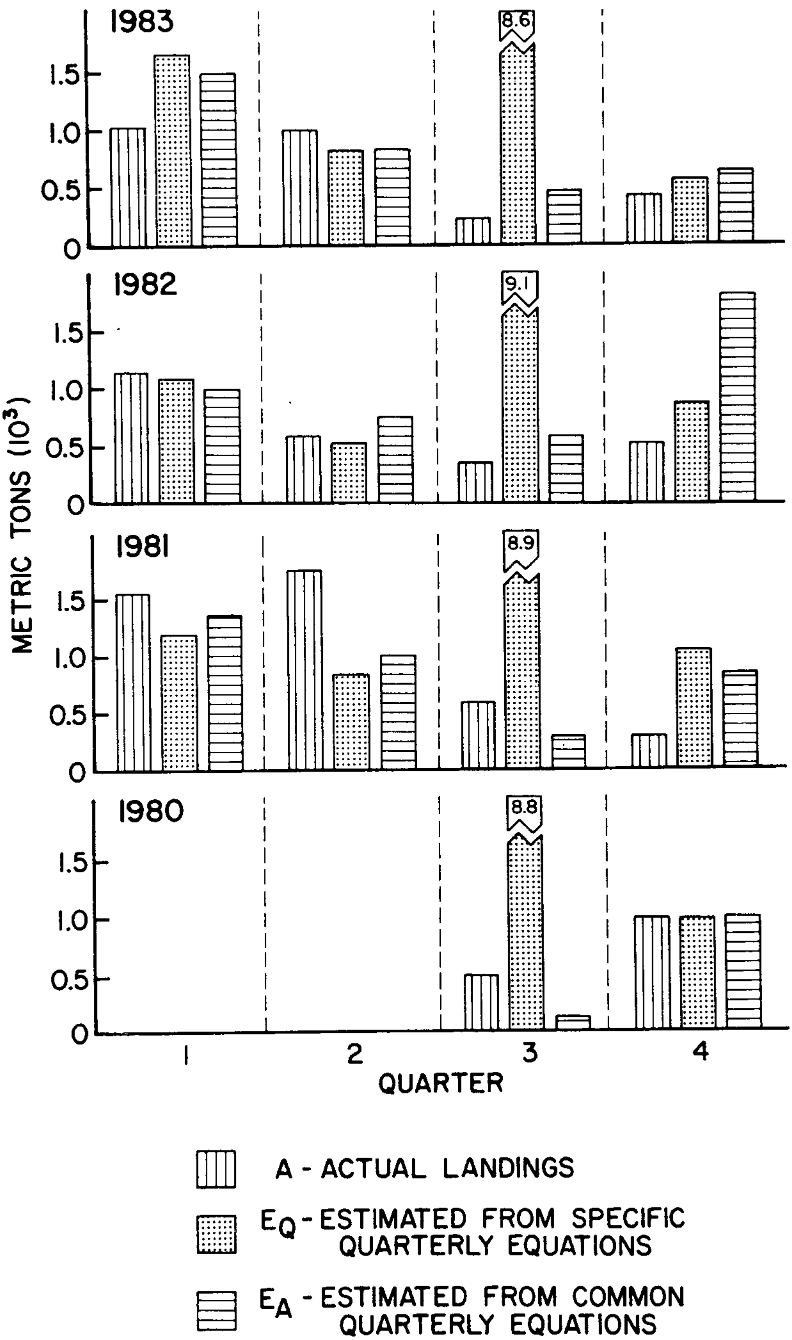


Figure 8. Quarterly landings from July–September 1980, through October–December 1984, from the records of the National Marine Fisheries Service (A) and as estimated from regression equations (E).

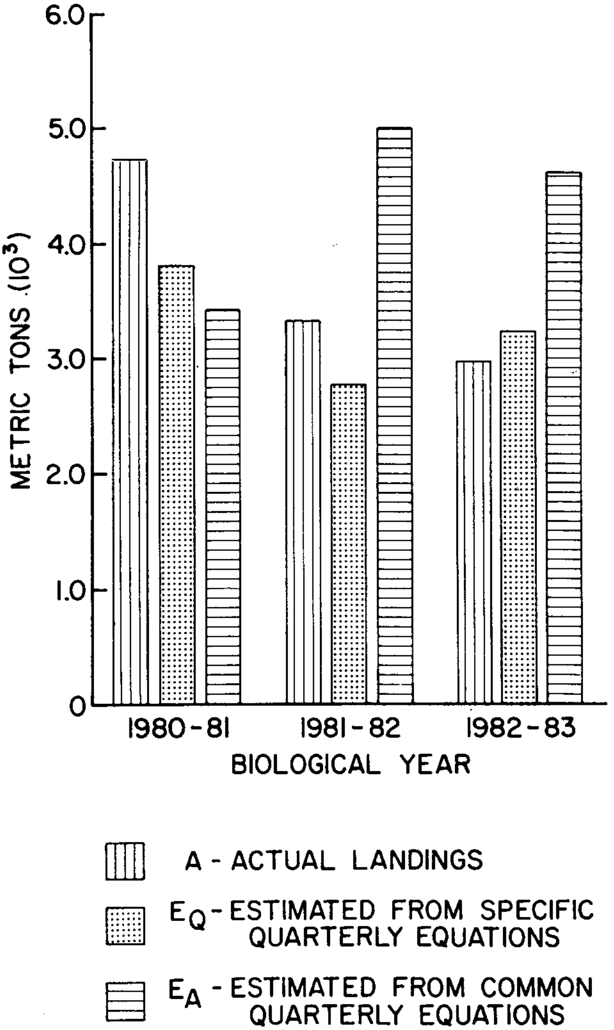


Figure 9. Annual landings for the biological years (July–June) 1980–1981, 1981–1982, and 1982–1983: from the records of the National Marine Fisheries Service (A), as estimated from quarterly regression equations (E_Q), and as estimated from the annual regression equation (E_A).

Figure 8 indicates that Quarter 3 estimates from the equation specific to that quarter (E_Q) are unrealistically high. Estimates from the equations specific to Quarters 1, 2, and 4 are similar to actual values. The equation common to all quarters gave unrealistically high landings estimates (E_A) for Quarter 4 of 1981 and 1982. The estimate for 1982 was influenced by an extremely high CPUE value (31.74 kg/h for C_{t-4}) that was outside the range of CPUE in the original data set (7.75–25.13 kg/h). Landings estimated with the equation common to all quarters (E_A) were similar to actual landings for Quarters 1 and 2. Because Figure 8 indicated that landings estimates from the equation specific to Quarter 3 were unrealistically high, the estimate from this equation was not used in the annual summations from the separate quarterly equations (E_Q) in Figure 9; instead, the

Table 4. Average landings, nominal effort, standardized effort, and average nominal and standardized catch-per-unit-effort (CPUE) for each quarter

	Landings		Nominal effort		Stand. effort		Nom CPUE	Stan CPUE
Quarter	kg	% Ann	h	% Ann	h	% Ann	kg	kg
1	1,333,946	37.4	156,452	40.0	128,184	40.6	8.60	10.36
2	791,366	22.2	99,112	25.4	79,600	25.2	8.01	9.96
3	369,057	10.3	35,369	9.0	29,539	9.4	10.70	12.76
4	1,075,140	30.1	99,919	25.6	78,478	24.9	10.76	13.87

Note: Quarter 1, landings: January through March 1967–1980; Quarter 2, landings: April through June 1967–1980; Quarter 3, landings: July through September 1966–1979; Quarter 4, landings: October through December 1966–1979.

longer-term average for Quarter 3 landings was used. Annual estimates from the equations specific to each quarter are fairly representative of actual figures. Annual estimates from the equation common to all quarters do not fit the actual data as well. Both 1981–1982 and 1982–1983 annual estimates from this equation were affected by unrealistically high estimates for Quarter 4.

Estimates from the specific equations for Quarters 1, 2 and 4 are as good as could be expected from regression equations. Multicollinearity may have biased the estimation of regression coefficients in the Quarter-3 equation. The estimate of standardized effort that was necessary in order to make the comparisons is an additional possible source of error.

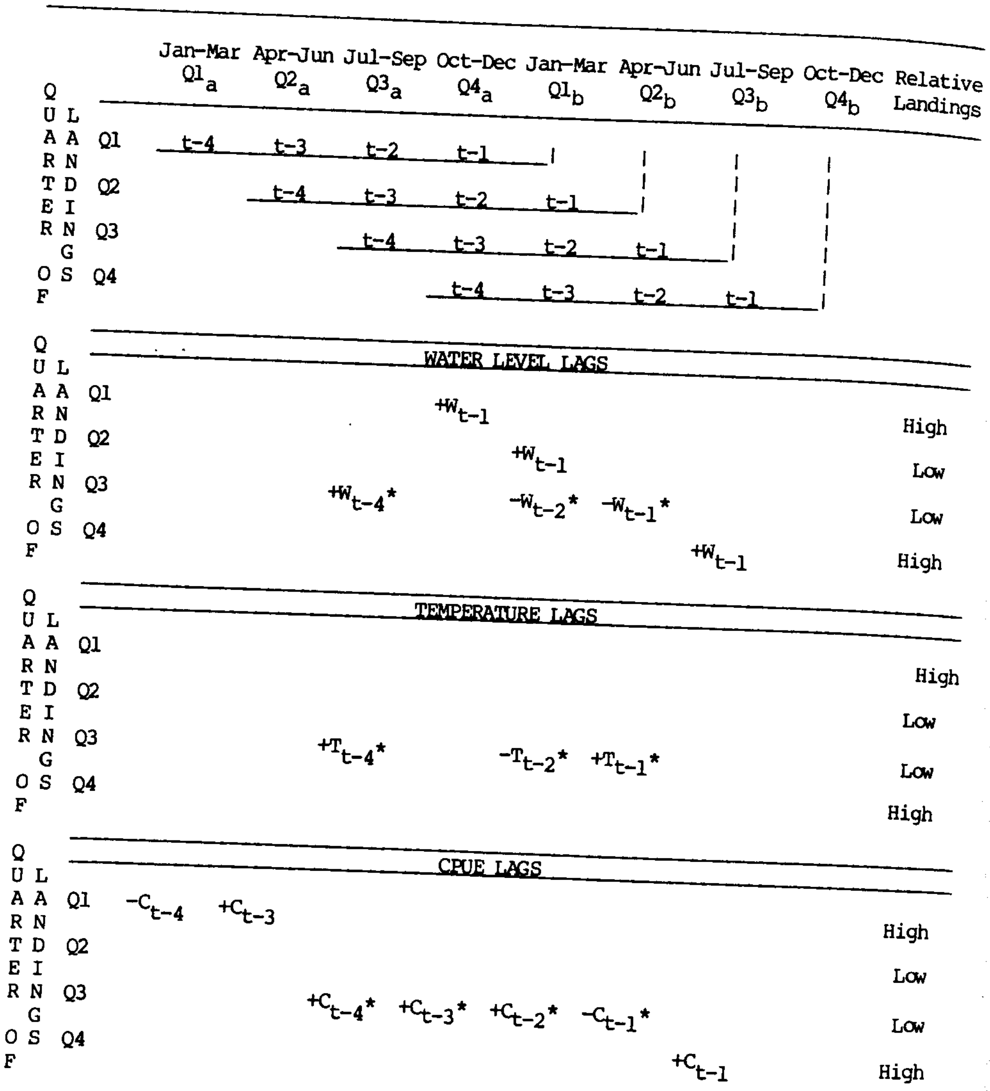
INTERPRETATION OF RESULTS

Catch and effort in the Tortugas pink shrimp fishery are highly seasonal. Two thirds of the annual landings from July 1966, through June 1980, was taken in Quarters 4 and 1 (October through March). Only one third was taken in Quarters 2 and 3. Peak landings occurred in Quarter 1, minimum landings in Quarter 3 (Table 4). The uneven distribution of the annual catch among quarters suggests that equations for Quarters 1 and 4 would be more important in explaining the annual shrimp catch than equations for Quarters 2 and 3.

Regression results suggest that October through March (rows Q4 and Q1 in Fig. 10) shrimp landings were associated with high freshwater discharges (indexed by water level) from July through December (columns $Q3_b$ and $Q4_a$). The equation for Quarter 2 (row Q2) suggests that freshwater discharges from January through March (column $Q1_b$) also have a positive affect on landings [the equation for Quarter 3 (row Q3) contradicts this, but this equation may not be reliable]. The possible effect on shrimp production of freshwater discharges during the spring (April–June, or column $Q2_b$) is not clear because the water level variable for this quarter was significant only in the equation for Quarter 3 (row Q3), and the signs of the regression coefficients in this equation may have no meaning because of multicollinearity.

Average air temperatures from April through June and from July through September were positively correlated with July through September (row Q3) landings. Air temperature from January through March (column $Q1_b$) was negatively correlated with July through September (row Q3) landings.

In the regression equations, catches from January through March (row Q1 in Fig. 10) were positively related to the stock of shrimp three quarters previously (column $Q2_a$, or April–June) and negatively related to stock four quarters previously (column $Q1_a$, or January–March). Negative correlation could indicate competition between the cohorts produced by January–March spawners and those produced by April–June spawners or by predation of older on younger cohorts.



*Signs of regression coefficients may be unreliable due to possible multicollinearity.

Figure 10. Statistically significant variables for each quarter from the four selected equations.

Much of the variation in landings could be explained by the water variable. Water level, lagged one quarter, explained 30% in Quarter 1, 68% in Quarter 2, and 48% in Quarter 4 of the variation in landings that was not explained by the effort variable (see last column in Table 5). In the equation for all four quarters, this variable explained 40% of the variation in landings not explained by effort.

I used the regression relationships just discussed to "predict" the quarterly and annual landings of pink shrimp that would occur under the range of average quarterly water levels experienced during the 14-year period of the data (Table 6). Average October through December water levels, used for predicting Quarter

Table 5. Proportion of variation in landings not explained by effort that was explained by variation in water levels one, two, three, or four quarters previously (last column)

Quarter	r^2_s	r^2_w	$1 - r^2_s$	$r^2_w/1 - r^2_s$
1*	0.5725	0.1282	0.4275	0.2999
2*	0.0921	0.6150	0.9079	0.6774
3†	0.0684	—‡	0.9316	—‡
4*	0.2609	0.3555	0.7391	0.4810
All*	0.7566	0.9803	0.2434	0.4027

* W is the one-quarter lag in water level.
† W is the one, two, and four-quarter lag in water level.
‡ This value was not available from regression results.

1 landings, varied from 44.5 to 85.6, with an average of 55.2 cm above mean sea level (MSL). The Quarter 1 (January–March) equation predicted that a 90% increase [100(85.6–44.5)/44.5] in water levels above minimum (i.e., to the maximum) could result in a 53% increase [100(1,749,905–1,145,179)/1,145,179] in landings.

Average water levels from January through March varied from 21.0 to 74.7, with a mean of 37.5 cm above MSL, for the 14-year period. The Quarter 2 (April–June) equation predicted a 64% increase in landings with a 255% increase in water levels.

Quarter 3 landings averaged 369,057 kg during the period analyzed. The effect of changing the average water level could not be evaluated for lack of a reliable equation relating landings to water levels.

July through September water levels varied from 47.9 to 82.6, with a mean of 61.3 cm above MSL. The Quarter 4 (October–December) equation predicted a 41% increase in landings with a 73% increase in water levels.

If water levels reached the maximum each quarter, annual landings of approximately 4,564,416 kg might be realized, according to the regression equations for Quarters 1, 2, and 4 (and assuming no change from average landings in Quarter 3). This is a 37% increase over the annual landings of 3,327,539 kg expected with minimum water levels each quarter.

According to the regression equations, water levels from October through December were more influential on total annual landings of shrimp than water levels from January through March or from July through September. Water levels from July through September were more influential than those from January through March. Within the ranges of data used in the analysis, raising average water levels 30.48 cm (1 ft) from October through December might increase annual shrimp production by approximately 34%. Raising average water levels 30.48 cm from January through March might increase annual shrimp production by approximately 7%. The same increase in average water levels from July through September might increase shrimp production by approximately 10%. (Water levels during the four quarters were not totally independent; coefficients of correlation of water levels between quarters varied from 0.34 to 0.77.)

The prediction of total annual landings under different water conditions from the equation common to all quarters was similar to the sum of the predictions for the three quarters (plus average landings for Quarter 3). The equation common to all quarters predicted annual landings of 3,195,287 kg with minimum water levels and 4,370,471 kg with maximum water levels (a 37% increase). Based on this equation, a 30.48 cm increase in water levels (above average or to maximum) throughout the year would increase annual shrimp landings by 24%.

Table 6. Predicted total quarterly landings (L) in kilograms from the equation for each quarter and the common equation for each quarter, using minimum, average, and maximum values for water level in centimeters above mean sea level, lagged one quarter (W_{t-1}), and quarterly average values for the other independent variables of each equation

Quarter of landings	Minimum		Average		Maximum	
	W_{t-1}	L_t	W_{t-1}	L_t	W_{t-1}	L_t
1	44.5	1,333,763	55.2	1,145,179	85.6	1,749,905
2	21.0	665,020	37.5	795,794	74.7	1,094,425
3*	28.7	(369,057)	41.8	(369,057)	73.2	(369,057)
4	47.9	959,699	61.3	1,110,738	82.6	1,351,029
Ann. total†		3,327,539		3,420,768		4,564,416
Ann. total‡		3,570,688		3,195,287		4,370,471

* Predictions for Quarter 3 were not attempted because of possible multicollinearity in the selected equation for this quarter. Average landings for this quarter (with no water effect) are shown here.
† Sum of predictions from the separate equations for each quarter.
‡ Sum of predictions from the equation common to all quarters.

Although the equation for Quarter 3 could not be used to quantify the possible effect of water level on landings, this deviant equation may contain noteworthy information about factors influencing pink shrimp landings. This equation incorporated the CPUE of all four previous quarters and both water level and air temperature for all but one of the four previous quarters. Quarter 3 (July through September) is the period of peak spawning for Tortugas pink shrimp. Fishing pressure at this time is low [because many vessels are fishing for brown and white shrimp (*Penaeus setiferus*) in the northern Gulf], and the population is on the upswing from the annual low that follows the peak fishing season (Quarters 4 and 1), during which effort has been directed primarily at the spawn of the previous year. All but the cohorts spawned during the previous two quarters (Quarter 1 and Quarter 2) would have been reduced by heavy fishing pressure. Because the cohort of Quarter 3 of the previous year was the major cohort of that year, it might still be an important component of this year's population, despite high fishing mortality. Perhaps Quarter 3 is the one time of the year when all four cohorts of the previous year are approximately equally represented in the population. This might be the reason why independent variables from all four quarters were important in explaining the variation in landings during Quarter 3. Examination of the size-frequency distribution of shrimp caught from July through September might determine whether several cohorts are indeed strongly represented in the stock at this time.

Although regression analysis does not prove cause and effect, this study suggests that freshwater runoff from the Everglades, as indexed by water level at Station P-35, probably influences Tortugas pink shrimp landings. The relationships indicated by these equations should not be extended beyond the range of data used in the analyses. These results should not be interpreted to mean that high water levels in *all* seasons of the year promote shrimp production. There is some suggestion—from the Quarter 3 equation—that low spring (April–June) water levels may enhance summer (July–September) shrimp landings. It is possible that, in any season, increases in water level beyond the range of these data could suppress rather than stimulate landings.

This was an exploratory study; additional data or other techniques might later be used to develop a more accurate quantitative description of the relationship between landings and water level.

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