Relationship between environmental factors and brown shrimp production in Pamlico Sound, North Carolina

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RELATIONSHIP BETWEEN ENVIRONMENTAL FACTORS AND BROWN SHRIMP PRODUCTION IN PAMLICO SOUND, NORTH CAROLINA

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CONTENTS

Abstract

A model is developed that predicts brown shrimp, *Penaeus aztecus*, harvest in Pamlico Sound, N.C. using environmental factors in late spring. Salinity and temperature conditions during April and May in the brown shrimp nursery areas are the most important parameters affecting harvest. Brown shrimp growth rates decrease and mortality rates increase at low salinities and temperatures. Ten parts per thousand and twenty degrees Celsius are found to be threshold levels below which harvest is poor and above which harvest is good. Using the early April salinity and temperature average values, two equations are developed that estimate values for these parameters through the end of May. Using the estimated parameter values and their interaction, two equations are developed that predict brown shrimp harvest. The salinity and temperature estimates can be replaced with bimonthly average values to update the model. An example of the model is presented for 1975. Other parameters possibly affecting brown shrimp are discussed.

INTRODUCTION

The brown shrimp, *Penaeus aztecus*, comprises the largest commercial shrimp harvest in North Carolina. Most of North Carolina's brown shrimp are caught in Pamlico Sound. The commercial value of this species has led to many studies of its biology and ecology. This report used the general results of those studies and specific data from the North Carolina Department of Natural Resources and Community Development to develop a statistical model to predict annual brown shrimp harvest in Pamlico Sound.

General Biology of *Penaeus aztecus*

Brown shrimp respond physiologically to changes in environmental variables. Zein-Eldin and Aldrich (1965) found in a laboratory experiment that growth and survival rates decreased at temperatures below 15°C. *Penaeus aztecus* postlarvae burrow into bottom sediments at temperatures below 18°C (Aldrich, Wood and Baxter, 1968). This burrowing probably increases survival but reduces growth rates. Results from field observations suggest that the optimum salinity range for postlarval brown shrimp is 10-30°/oo (Gunter, *et al*., 1964).

As a result of the impact of salinity and temperature on shrimp growth and behavior, hydrologic conditions in the nursery areas are a major factor in shrimp survival and population size. Barrett and Gillespie (1973) found that brown shrimp harvest in Barataria Bay was correlated with the number of hours after April 8 in which the water temperature was below 20°C. These same authors also found that favorable conditions for brown shrimp occurred when salinities were above 15°/oo.

Rainfall and river discharge influence nursery area salinity profiles. Total rainfall in March and April affects brown shrimp harvest in Louisiana

(Barrett and Gillespie, 1973), with poor harvests occurring in years with heavy rainfall. Also Barrett and Gillespie (1976) found high brown shrimp harvests in years with low Mississippi River discharge.

The harvest of commercial species other than shrimp are also correlated with salinity and temperature fluctuations in their environment. Sutcliffe (1972, 1973) found increased catches of lobster to be associated with high river flow in the Gulf of St. Lawrence. He felt that production was increased due to increased nutrient concentrations in the water during high flow periods. In Lancashire, England, rainfall affects population size of *Crangon crangon* (Driver, 1976).

Other factors influencing harvest may be the number of acres of intertidal vegetation (Turner, 1977), net heating degree days (Williams, 1969), and predation (Barrett and Gillespie, 1973).

The statistical model described in this paper is based on known aspects of brown shrimp biology and environmental and harvest data from Pamlico Sound, North Carolina. Extensive prior knowledge of *Penaeus aztecus* biology and the isolated nature of the Pamlico Sound population contributed substantially to our ability to develop an effective harvest model, but extrapolation of this model to other brown shrimp populations should be done with caution, because in less isolated areas the harvest data may be collected in areas quite removed from the nursery areas making correlation of the harvest with nursery area environmental data impossible.

STUDY AREA

The brown shrimp (Penaeus aztecus) nursery areas are located in the small bays and tributaries of western Pamlico sound from Adams Creek in the south to Stumpy Point in the north (See Fig. 1). Salinities range annually from 4^{o}/oo to 20^{o}/oo and water temperatures from 4^{o}C to 30^{o}C. Substrates are predominately fine grained muddy sand.

Brown shrimp are harvested outside the nursery areas, but totally within Pamlico Sound.

BIOLOGY OF PENAEUS AZTECUS IN PAMLICO SOUND

Penaeus aztecus ranges from Martha's Vineyard, Massachusetts to the Yucatan peninsula in Mexico. However, Pamlico Sound, North Carolina represents the northernmost breeding population.

Penaeus aztecus has an annual life cycle. The adults spawn offshore in the early spring with a peak in February and March (Perez Farfante, 1969). The larvae and postlarvae migrate through the inlets on the flood tide (Roessler and Rehrer, 1971) into Pamlico Sound, and from there move across the sound, presumably with wind driven currents, to the nursery areas. The postlarvae molt to the juvenile stage 4-6 weeks after entering the estuaries (Perez-Farfante, 1969). The brown shrimp postlarvae preferentially select softer-muddier substrates (Williams, 1958) in the upper estuaries. Here, they grow rapidly until the mid to late summer, when they leave the nursery area. Tagging experiments (Purvis and McCoy, 1974, McCoy, 1968) have shown that the shrimp migrate into southern Pamlico Sound upon maturity. These studies further indicate that the mature brown shrimp are migrating toward the nearest inlet.

The juvenile brown shrimp grow from approximately 15 mm in early May to 115 mm at the time they begin their adult migration. They are omnivores, eating live material and detritus, and are preyed upon by carnivorous fishes and larger crustaceans.

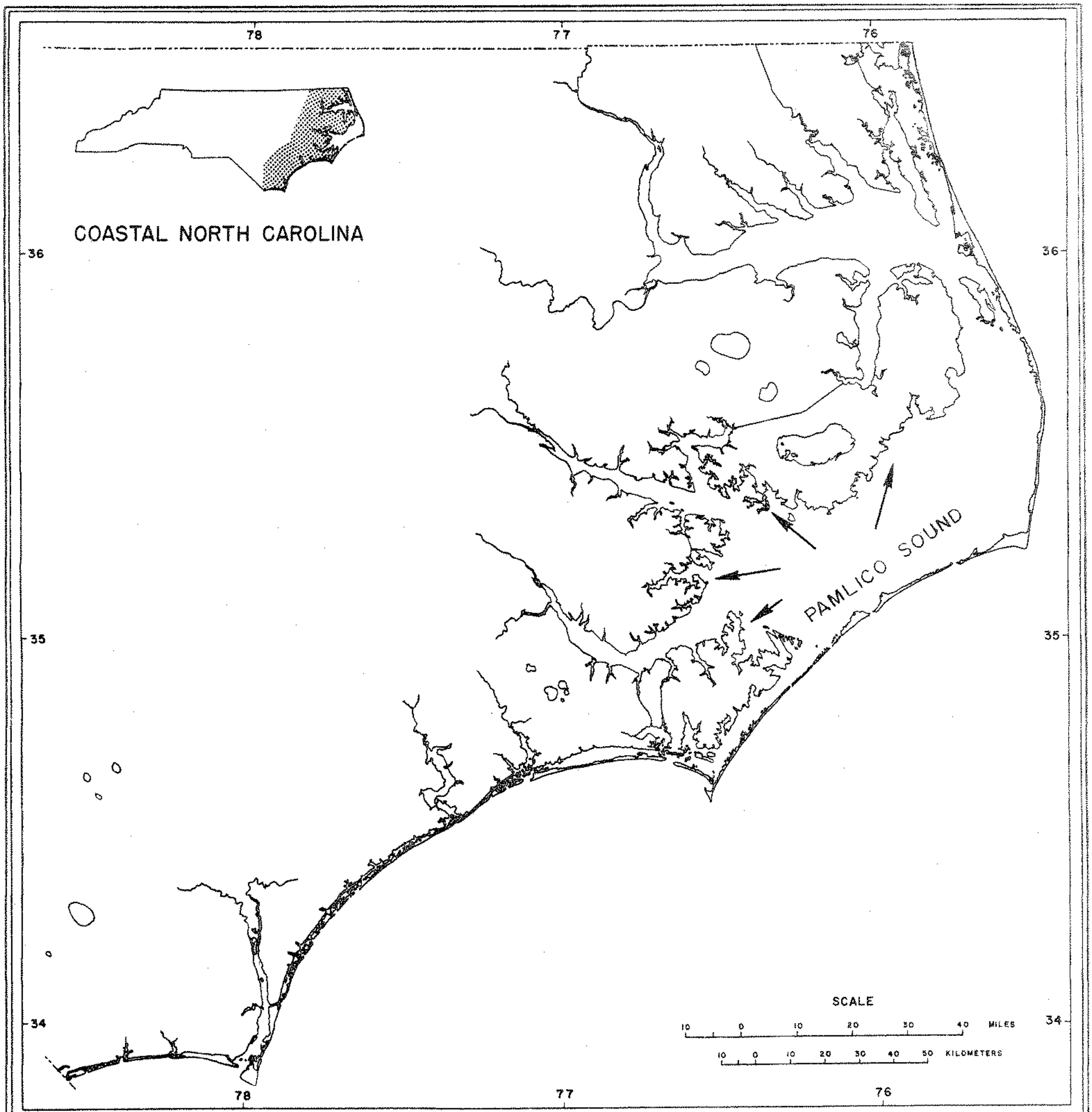

Figure 1. - Location of brown shrimp nursery areas in Pamlico Sound. The arrows indicate the general locations of the nursery areas in the small bays and creeks of western Pamlico Sound.

MATERIALS AND METHODS

The data for this model are environmental variables. These include shrimp harvest, salinity, water temperature, juvenile abundance in nursery areas, river discharge, air temperature, precipitation, heating degree days, and wind speed and direction. The data were supplied by the following agencies for the years listed.

Harvest - Monthly - 1968-1977 Yearly - 1955-1968

National Marine Fisheries Service

Variable	Years	Source
Salinity	1972-1977	NC Division of Marine Fish.
Water Temperature	1972-1977	"
Juvenile Abundance	1972-1977	"
Air Temperature	1955-1977	National Climatic Center
Precipitation	1955-1977	"
Heating Degree Days	1955-1977	"
Wind Velocity & Direction	1955-1977	"
River Discharge	1954-1977	United States Geological Survey

Salinity, water temperature and juvenile abundance were measured in the nursery areas. Wind speed and direction, precipitation, air temperature and heating degree days were measured at Cape Hatteras. River discharge was measured at two locations, the Neuse River at Kinston and the Tar River at Tarboro.

The models were built using multivariate regression techniques, on the UNC Computer (IBM 360/75 and 370/155).

RESULTS

Brown shrimp harvest in Pamlico Sound for the years 1972-1977 ranges from 1,181,000 pounds to 2,644,000 pounds. Fishing effort each year was approximately constant (C. Purvis, personal comment). Examination of Table 1 indicates that one year's harvest does not affect the harvest in the following year. This is in contrast to Driver (1976), who found the catch of *Crangon crangon* in one year is highly correlated with the following year's catch.

Juvenile abundance in the nursery areas is highly correlated ($r = .94$) with harvest. This correlation coefficient is probably unrealistically high due to the small sample size, but examination of the data indicates a positive relationship between juvenile abundance and harvest (Table 2).

Water temperature and salinity are the two environmental variables that have the greatest correlation with brown shrimp harvest in Pamlico Sound. Consistent with Gunter *et al*. (1964) observations on salinity and Aldrich *et al*. (1968) reports on temperature and burrowing behavior, our data analysis indicates that 10°/oo and 20°C are threshold values that can be usefully incorporated into shrimp harvest prediction models (Figure 2). During the critical time of postlarval settlement and first juvenile growth (April and May), the salinity and temperature values fluctuate around these threshold levels. The highest temperature values in each year are those from late May, at the end of the critical time period. Years with low salinity and temperature values have poor harvests and conversely for high salinity and temperature values. The salinity values are particularly striking. For example; 1975, a year of poor harvest, had salinity and temperature values below the threshold levels for all periods except late May. Conversely, in 1976, a good year, both salinity and temperature values were consistently above threshold levels. Salinity seems to be the dominant factor, but there are also indications of interactions between salinity and temperature. For example, in 1972 salinity

Table 1. - Monthly harvests of brown shrimp in Pamlico Sound, NC, in lb (x1000).

	1972	1973	1974	1975	1976	1977
June	2.2	0	84	45	64	0
July	142	373	341	360	958	1,257
August	900	390	1,649	481	934	987
September	415	280	291	153	473	300
October	139	175	116	132	108	100
November	7.7	16.6	7	9.9	3.2	0
TOTAL	1,606	1,235	2,488	1,181	2,540	2,644

Table 2. General relationship between brown shrimp harvest in Pamlico Sound, NC, juvenile abundance, and environmental factors.

Year	Harvest/1000	Juvenile Abundance/2 in Late May	Salinity in Late April	Temperature in Late April	Knot Hours Late April Early May	Stor
1972	1,606	11.0	8.2	20.0	129	-18
1973	1,235	3.9	6.5	20.6	-775	-66
1974	2,488	37.8	10.8	20.6	-18	22
1975	1,181	11.3	9.5	18.7	257	-36
1976	2,540	53.0	12.1	24.1	-485	-28
1977	2,644	42.4	13.0	20.2	-824	-120

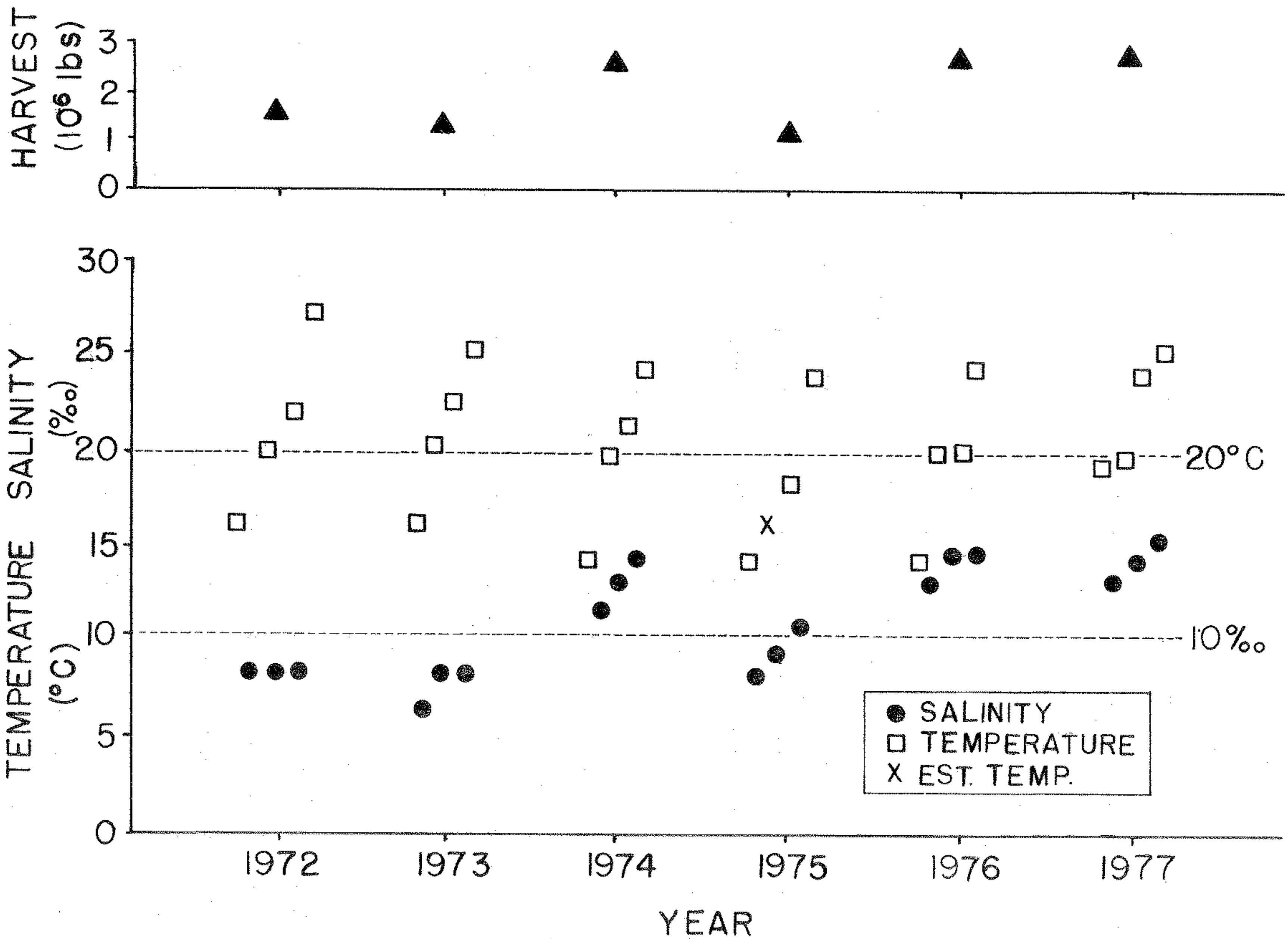

Figure 2. - Relationship between salinity, temperature and brown shrimp harvest. Salinities are recorded for late April-late May. Temperatures are recorded for early April-late May. 10% and 20°C are threshold values for salinity and temperature.

values are below 10°/oo but temperatures are dominantly above 20°C; the harvest was 1,606,000 pounds, i.e. somewhat higher than 1975. Interactions between salinity and temperature were observed in the acclimatization experiments of Wiesepape, et al. (1972). These observations lead to the more detailed analyses presented later in the paper.

Five years of salinity data show a repeatable fluctuation of salinities (Figure 3). Salinity generally decreases until early April, then increases dramatically, often as much as 1-2°/oo in a few weeks. This repeatable trend enabled us to develop a model to predict all salinity values in the critical time period; late April through the end of May. The value for salinity in early April and a linear time trend beginning in early April, denoted as T elapse, are the basis of a model predicting the rise in salinity during the critical time period. T elapse is defined as:

T elapse = 0 if T period $\leq$ 9

T elapse = T period - 9 otherwise

T period is a time period separating device defined as 2 times the month plus the perios (2 x month + period), such that for period 1 (early) in April T period = 9.

The resulting model is:

Eq. 1. Sal 2 - 2.03 + .75 Sal 1 + .46 T elapse; R^2=.72.

When predicting the late April salinity (T period = 10) Sal 1 is the actual average nursery area salinity for early April. Otherwise, Sal 1 is defined as the actual or estimated salinity in the time period immediately preceeding that of Sal 2.

Equation 1 adequately models the average salinity trends during the critical time period (Figure 3), but overestimates the late May observations in low salinity years and underestimates them in high salinity years. This model

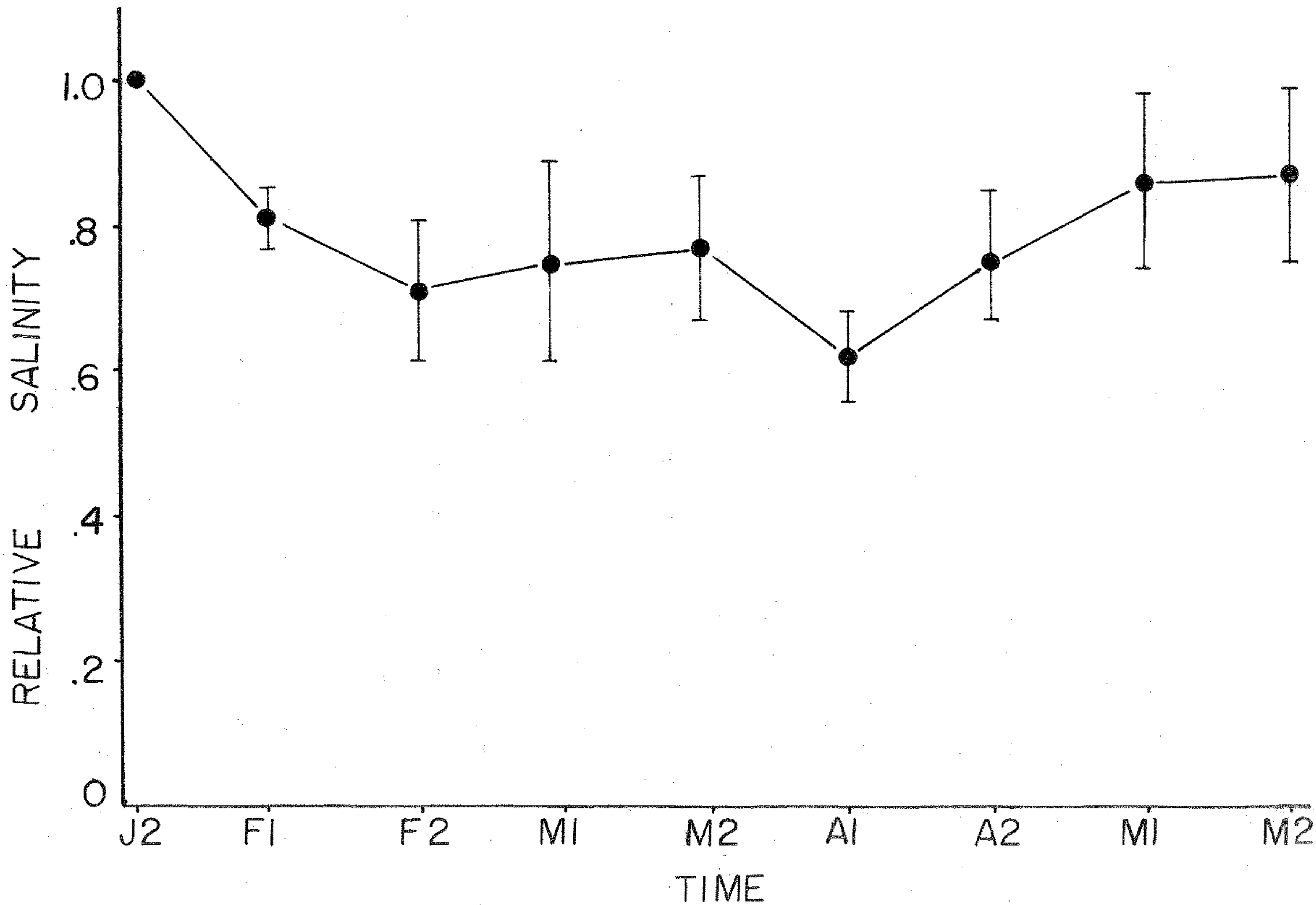

Figure 3. - Average salinity trend for the years 1973-1977. All values are relative to the second half (late) of January (J2). In 1972, sampling did not begin until April. Vertical bars are 95% confidence intervals about means.

Table 4. - Model for predicting water temperature in brown shrimp nursery areas during late April-May.

(N = 29, MSE = 3.50)

Parameter	Estimate	Std Error	Pr > |T|	R^2	R^2_p
Intercept	-1.41	2.20	.53	.80	.72
TEMPI	.095	.16	.56		
T PERIOD	1.91	.43	.0001		

YEAR	MONTH	PERIOD	TEMP	MODEL ESTIMATE
1972	4	1	16.3	16.3
		2	20.0	19.2
	5	1	22.0	21.4
		2	----	23.59
1973	4	1	16.2	16.2
		2	20.6	19.2
	5	1	23.1	21.4
		2	25.0	23.5
1974	4	1	14.4	14.4
		2	19.6	19.1
	5	1	20.9	21.4
		2	24.0	23.5
1975	4	1	13.6	13.6
		2	18.7	19.0
	5	1	----	21.4
		2	25.3	23.5
1977	4	1	21.1	21.1
		2	20.2	19.7
	5	1	23.8	21.5
		2	24.8	23.5

by moving the postlarvae toward the nursery areas and wind from the westerly section (215°-335°) should have a negative effect. Two methods were employed, knot hours and storm events. Knot hours is defined as the difference between the sum of the speeds of all easterly wind and the sum of the speeds of all westerly wind in any east or west wind event in a biweekly period. Storm events are wind events multiplied by the precipitation for the given day.

The data (Table 2) indicate no linear relationship between wind events and juvenile abundance. While some non-linear relationship may be present, it is probably masked by salinity and temperature effects. As well, the addition of knot hours and storm events never added any significant predictive power to harvest models.

Discharge from the Neuse and Pamlico Rivers is an important parameter in determining salinities in the nursery areas. Periods of very high discharge generally decrease salinities. A regression equation was developed using salinity in one time period and river discharge to predict salinity in the next time period (Table 5). The discharge, a linear time trend (T period) and the previous salinity value are entering terms for this model. While demonstrating the role of discharge in determining salinity, this equation was not useful for prediction of harvest due to the limitations in its ability to predict several time periods in the future. Thus we used the average annual salinity pattern (Figure 3) to forecast future salinities.

Table 5. - Regression equation for prediction of salinity using river discharge data.

Sal 2 = 25.34506 + .67489 Sal 1 + -.85319 Dschg + -.20910 T period

ANOVA TABLE

Parameter	Estimate	Std Error of Estimate	T for HO: Parameter=0	PR > |T|
INTERCEPT	25.34506	3.82	6.64	.0001
SAL 1	.67489	.06	11.45	.0001
DSCHG	-.85319	.13	-6.58	.0001
T PERIOD	-.20910	.09	-2.34	.0248

R^2 = .87, N = 40

HARVEST MODEL

Harvest variability is related to variability in survival and growth, making salinity and temperature useful variables in developing a harvest model for brown shrimp, because they are two important factors affecting survival.

The terms of the model are defined as follows:

Salhat - Estimated values from Eq. 1 + correction factors
Temphat - Estimated values from Eq. 2 + correction factors
Interact - Salhat x Temphat/10

SALI These are average values generated
TEMPI from Salhat, Temphat, Interact.
INTERAI Each variable has four values.

For example:

(i) SALI matched with July is the average of Salhat for late April and early May.
(ii) SALI matched with August is the average of Salhat for early May and late May.
(iii) SALI matched with September is Salhat for late May.
(iv) SALI matched with October is the average of Salhat for late April through late May.

S1 = threshold value for salinity = 10°/oo
T1 = threshold value for temperature = 20°C

J7 = min (Interact - T1) if Salhat < S1 and Temphat < T1 in one of the periods from late April through late May

= 0 otherwise

J12 = min (SALI - S1) if Salhat < S1 for all periods from late Apirl through late May

= 0 otherwise

The terms J7 and J12 are defined so as to be sensitive to the threshold levels of salinity and temperature. These are important terms in the model for they allow us to distinguish between above and below average years. When the conditions are such that J7 and J12 are not equal to zero, they are computed in the following manner:

$$J7 = \min[19.7, \max(H, 17.5)]-20$$

$$H = \frac{3\ \text{INTERAI (July)} + \text{INTERAI (August)}}{4}$$

Thus, if H falls between 17.5 + 19.7, then J7 = H - 20. However, the boundaries of J7 are limited by the maximum value of 19.7 - 20 and the minimum of 17.5 - 20.

$$J12 = \min \{9.7, \max (G, 8.5)\} - 10.$$

$$G = \frac{\max (SALI) + \min (SALI)}{2}$$

Thus, if G falls between 8.5 and 9.7, then J12 = G -10. However, the boundaries of J12 are limited by the maximum value of 9.7 - 10 and the minimum of 8.5 - 10.

There are two equations that are used to predict harvest. They are designed to predict the deviation from the monthly average yield. The monthly averages are computed for the years 1968-1977.

MONTH	AVEYIELD (Hundreds of thousands of pounds)
July	5.722
August	8.752
September	3.388
October	1.423
TOTAL	19.285

Two regression equations are presented that predict brown shrimp harvest in Pamlico Sound.

The first (Model 1) is:

Eq. 3 YIELD - AVEYIELD = 1.5384 + 1.1998 J12 + 1.587 J7

Model 1 is very sensitive to the threshold values of salinity and temperature. It discriminates below average years very well. However, because J7 and J12 = 0 in good years, it does not discriminate between good years. (Table 6).

The second (Model 2) is:

Eq. 4 YIELD - AVEYIELD = -4.0118 + .41794 SALI + 1.08498 J7

Model 2 discriminates good years quite well. Its discriminatory characteristics are centered in the second term (SALI), because this term is not affected by

Table 6. - Comparisons of predicted versus true harvest for models 1 and 2 (x 100,000 pounds).

Year	True harvest	Model 1	Model 2
1972	15.96	15.36	16.23
1973	12.18	12.96	16.41
1974	23.97	25.44	23.73
1975	11.26	9.34	9.63
1976	24.73	25.44	25.84
1977	26.44	25.44	27.20

the salinity threshold. Because of the second term, this model has an emphasis on salinity, especially in good years when J7 = 0. This is consistent with our results (Figure 2) which indicate that brown shrimp may respond readily to changes in salinity. Analysis of variance data are in Table 7.

Using these models as a basis for predicting brown shrimp harvest, the following algorithm for computing harvest is presented.

Step 1. Using equations 1 and 2 generate estimated salinity and temperature values for late April through late May from the measured early April average salinity and temperature. If the early April salinity measurement is less than 10^o/oo, subtract .20 from the salinity estimate in early May and .50 from the salinity measurement in late May. Further, add .50 to the temperature estimate for late April if that estimate is below 20^oC, but the final value should not exceed 19.99^oC. Call these estimates Salhat and Temphat.

Step 2. Compute the values for SALI, TEMPI, and INTERAI.

Step 3. Compute the values for J7 and J12.

Step 4. Using equation 3 determine the estimates for the deviation from the monthly average from Model 1.

Step 5. Repeat step 4 with equation 4 for Model 2.

Step 6. Take the average of Steps 4 and 5 and add this to the monthly average yield. This is the monthly harvest.

Step 7. Calculate the sum of the monthly harvest. This is the estimated yearly harvest.

Step 8. If the estimated harvest is less than 900,000 pounds, replace the estimate by 900,000 pounds.

The prediction from this harvest is conservative. Equation 1 regresses towards the mean. While the Salhat estimates are lowered in late April and early May, these estimates still remain somewhat conservative. This feature of the model, in association with its direct relationship to brown shrimp biology provide sound estimates of harvest that are biologically meaningful.

Table 7. - Analysis of variance tables for models 1 and 2.

Model 1

$R^2 = .88$

SOURCE	ESTIMATE	STD ERROR	Pr > |T|
INTERCEPT	1.5384	.59	.01
J7	1.587	.59	.01
J12	1.1998	.47	.02

Model 2

$R^2 = .69$

SOURCE	ESTIMATE	STD ERROR	Pr > |T|
INTERACT	-4.0118	2.48	.12
SAL 1	.41794	.21	.06
J7	1.08498	.61	.09

EXAMPLE OF THE MODEL

1975 was selected for the example. 1975 critical time period salinities and temperatures were below threshold levels. Harvest was below average.

Step 1: Calculate the values for Salhat, Temphat and Interact.

Salhat and Temphat are the estimated values for salinity and temperature calculated with Eqs. 1 and 2 respectively and the appropriate correction factors discussed in the algorithm.

Using Eq. 1

$$\text{Sal } 2 = 2.03 + .75 \text{ Sal } 1 + .46 \text{ T elapse}$$

compute the salinity estimates. When calculating the estimate for late April, Sal 1 is the measured salinity value in the nursery areas for early April. When calculating the early May estimate, Sal 1 is the salinity estimate for late April, etc. For example:

1) To calculate the late April salinity estimate

$$\text{Sal } 1 = 7.7$$

$$\text{T elapse} = \text{T period} - 9 = 1$$

$$\text{Sal } 2 = 2.03 + .75(7.7) + .46(1) = 8.27$$

2) To calculate the early May salinity estimate

$$\text{Sal } 1 = 8.27$$

$$\text{T elapse} = 2$$

$$\text{Sal } 2 = 2.03 + .75(8.27) + .46(2) = 9.15$$

3) To calculate the late May salinity estimate

$$\text{Sal } 1 = 9.15$$

$$\text{T elapse} = 3$$

$$\text{Sal } 2 = 2.03 + .75(9.15) + .46(3) = 10.27$$

If the early April salinity measurement is $<10^{o}/oo$, then subtract .2 from early May and .5 from late May. Salhat is the corrected value of the salinity estimate.

Time Period	late April	early May	late May
Sal 2	8.27	9.15	10.27
Correction Factor	0	- .2	- .5
Salhat	8.27	8.95	9.77

Using Eq. 2.

Temp 2 = −1.42 + .095(Temp 1) + 1.91(T period)

compute the temperature estimates. Repeat the proceedure used for calculating the salinity estimates.

Time Period	late April	early May	late May
Temp 1	13.6	18.97	21.39
T period	10	11	12

late April: Temp 2 = −1.42 + .095(13.6) + 1.91(10) = 18.97

early May: Temp 2 = −1.42 + .095(18.97) + 1.91(11) = 21.39

late May: Temp 2 = −1.42 + .095(21.39) + 1.91(121) = 23.53

If the early April temperature is <20°C, then add .5°C to the late April temperature estimate, but this should not exceed 19.99. Temphat is the corrected value of the temperature estimate.

Time Period	late April	early May	late May
Temp 2	18.97	21.39	23.53
Correction Factor	+ .5	0	0
Temphat	19.47	21.39	23.53

Compute Interact in the following manner.

Interact = Salhat x Temphat/10.

late April Interact = (8.27 x 19.47)/10 = 16.10

early May Interact = (8.95 x 21.39)/10 = 19.14

late May Interact = (9.77 x 23.53)/10 = 22.98

Step 2: Calculate the values for SALI, TEMPI, and INTERAI

SALI, TEMPI, and INTERAI are averages of Salhat, Temphat and Interact, and are used in computing the harvest estimate. All are calculated in the same manner. SALI is used here as the example.

(i) SALI matched with July is the average Salhat for late April and early May.
(ii) SALI matched with August is the average of Salhat for early May and late May.
(iii) SALI matched with September is Salhat for late May.
(iv) SALI matched with October is the average of Salhat for late April through late May.

Using the above definitions, SALI is computed as follows.

July $(8.27 + 8.95)/2 = 8.61$

August $(8.95 + 9.77)/2 = 9.36$

September $= 9.77$

October $(8.27 + 8.95 + 9.77)/3 = 9.00$

TEMPI and INTERAI are calculated similarly. Their values are presented in Table 8.

Step 3: Calculate the values for J7 and J12.

J7 = 0 if Salhat ≥ 10 and Temphat ≥ 20 in all time periods from late April through late May. If not, J7 is calculated by the following equations:

$$J7 = H - 20$$

where

$$H = \frac{3\text{ INTERAI (July)} + \text{INTERAI (August)}}{4}$$

In 1975, the values of Salhat and Temphat in late April are <10. $J7 \neq 0$ and is calculated by:

$$H = \frac{3(16.10) + 19.14}{4} = 18.48$$

$$J7 = 18.48 - 20.00 = -1.52$$

J12 = 0 if Salhat ≥ 10 for any time period from late April through late May. If not, J12 is calculated by the following equations:

$$J12 = G - 10$$

where

$$G = \frac{\text{max SALI} + \text{min SALI}}{2}$$

In 1975, Salhat is never $\geq$ 10. J12 $\neq$ 0 and is calculated by:

$$G = \frac{9.77 + 8.61}{2} = 9.19$$

$$J12 = 9.19 - 10 = -0.81$$

Step 4: Calculate the deviation from the average monthly harvest for Model 1.

Yield - Aveyield = 1.5384 + 1.1998(J12) + 1.587(J7)

Yield - Aveyield = 1.5384 + 1.1998(-0.81) + 1.587(-1.52)

Yield - Aveyield = -1.85

The deviation will be the same for each month because J7 and J12 are independent of the time periods.

Step 5: Calculate the deviation from the average monthly harvest for Model 2.

Yield - Aveyield = -4.0118 + .41794(SALI for month) + 1.08498(J7)

July Yield - Aveyield = -4.0118 + .41794(SALI) + 1.0849807

July Yield - Aveyield = -2.06

The results are as follows:

	July	August	September	October
Yield-Aveyield	-2.06	-1.75	-1.58	-1.90

Step 6: Calculate the monthly harvest.

Monthly harvest is calculated by taking the average of Steps 4 and 5 for each month and adding this value to the average harvest for that month.

$$\text{Monthly harvest} = \frac{\text{Deviation (Model 1)} + \text{Deviation (Model 2)}}{2} + \text{Aveyield}$$

For July:

$$\text{July harvest} = \frac{-1.85 + -2.06}{2} + 5.722$$

$$\text{July harvest} = 3.762$$

Monthly harvests are:

	July	August	September	October
Harvest	3.762	6.952	1.668	0

Step 7: Calculate yearly harvest.

$$(3.762 + 6.952 + 1.668 + 0) \times 10^5 \text{lbs.} = 1{,}238{,}000 \text{ lbs.}$$

Table 8 is a summary of this example.

After each successive time period, the measured salinities and temperatures in the nursery areas can be substituted for the estimates made in this model. The harvest is then recalculated. This will be especially important in years where environmental conditions during the critical time period are such to drastically change salinity and temperature in the brown shrimp nursery areas.

ACKNOWLEDGEMENTS

We thank Connell Purvis, Dennis Spitsbergen, and Mike Street for their comments on brown shrimp biology. Katy West provided constructive criticism of the example. We thank Will Ambrose and Rick Deriso for reviewing earlier drafts of the manuscript.

Table 8. - Example of use of the harvest model to predict the 1975 brown shrimp harvest in Pamlico Sound, NC.

YEAR - 1975

Period	Late April	Early May	Late May	
Salhat	8.27	8.95	9.77	
Temphat	19.47	21.39	23.53	
Interact	16.10	19.14	22.98	
Month	July	August	September	October
SALI	8.61	9.36	9.77	9.00
TEMPI	20.43	22.46	23.53	21.46
INTERAI	17.62	21.05	22.98	19.41
J7	- 1.52	- 1.52	- 1.52	- 1.52
J12	- .81	- .81	- .81	- .81
Aveyield	5.722	8.752	3.388	1.423
Estimate of Yield-Aveyield From (Model 1)	- 1.85	- 1.85	- 1.85	- 1.85
Estimate From (Model 2)	- 2.06	- 1.75	- 1.58	- 1.90
Average of Last Two	- 1.96	- 1.80	- 1.72	- 1.88
Last + Aveyield	3.762	6.952	1.668	0.00

Estimated Yearly Harvest = 12.38×10^5 lbs.

True Yearly Harvest = 11.26

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