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BIOECONOMIC EVALUATION OF MIXED PENAEID SHRIMP IN PAMLICO SOUND

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[3]This report should not be considered as a publication. Data contained herein are subject to further analyses and interpretation.

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INTRODUCTION

In many estuarine areas of North Carolina, two species of penaeid shrimp are present simultaneously in commercially significant numbers, but with only one species of commercial size. The smaller pre-commercial sizes are usually discarded overboard during shrimping activities for the commercial sizes. Application of management techniques resulting from shrimp research has reduced the discard or loss of small, pre-commercial shrimp in most of the smaller estuarine areas (Purvis and McCoy, 1972). This loss still occurs, however, primarily in the larger Pamlico and Core Sound estuaries during late summer and fall when pre-commercial size pink shrimp enter the catches during the brown shrimp season.

The annual loss of pre-commercial shrimp discarded or otherwise destroyed under the above conditions is not known. It is reported that, at times, as much as 50 percent (by weight) of catches in Pamlico Sound may consist of precommercial size pink shrimp that are usually discarded overboard during late August to November. Many of the pink shrimp reach commercial size during the late fall season and are utilized.

It has been determined that pink shrimp overwinter in North Carolina estuaries, with major commercial concentrations remaining in Core, Bogue, and southern Pamlico Sound the following spring (Purvis and McCoy, 1972). The entire spring pink shrimp fishery is dependent on the overwintering survivors.

Shrimp management objectives held by the North Carolina Division of Marine Fisheries have been to (1) protect the resources, (2) optimize utilization, and (3) maximize economic yield when possible. The first of these objectives has been achieved by regulating the harvest and by regulating the alteration of the coastal zone. The second and third objectives have been more difficult. However, biologists have attempted to attain these goals by regulating the size of shrimp harvested. Unstable economic conditions locally and nationally have created a greater need to economically evaluate shrimp resources.

The management problem is to time the harvest of the shrimp resource so as to maximize economic yield to the fishery. The simultaneous presence of two shrimp species, only one of which has attained marketable size, requires that a choice must be made between present and future income. Harvesting brown shrimp when pre-commercial sized pinks are destroyed and discarded in the harvesting process represents a sacrifice of future income because the number of pink shrimp potentially available for capture later in the fall or next spring has been reduced. However, restricting shrimping activity in an effort to reduce pink shrimp discard represents a loss in present income if the restrictions result in a reduction in brown shrimp landings. Thus, in selecting the "best" management policy, the decision-maker must weigh the reduction in present income against the potential increase in future income that would result from adopting that management strategy.

The objective of the biological phase of the study was to document the effects of harvesting commercial-sized brown shrimp on sub-commercial pink shrimp during late fall, and to determine survival of overwintering pink shrimp during the following spring.

The purpose of the economics study was to specify a framework within which alternative public policy actions concerning pink shrimp discard can be evaluated. The emphasis was on: (I) developing an economic model by which management decisions can be guided; (II) identifying the relevant biologic and economic information required to estimate the value of pink shrimp discarded during the brown shrimp season, and the value of reduced brown shrimp landings that would result from implementing selected management policies; and (III) estimating the net economic gains to be realized by the North Carolina shrimp fishery due to adoption of selected management strategies designed to reduce the level of discard.

I. Biological

STUDY AREA

Pamlico Sound, North Carolina's largest estuary, is the most important pink shrimp area in the state (Figure 1). It is bordered by the mainland and its tributary rivers (Pamlico, Pungo, and Neuse Rivers) on the western side. The eastern side is formed by the outer banks with their three inlets: Oregon, Hatteras, and Ocracoke. At the northern end it connects with Albemarle Sound via Croatan and Roanoke Sounds which are separated by Roanoke Island. At the southern end Pamlico Sound is continuous with Core Sound.

Pamlico Sound is approximately 60 miles long and 15 to 20 miles wide, being narrowest at the northern end (9 miles) and widest opposite Hatteras Island (26 miles). Pamlico Sound and its tributaries total more than 1.25 million acres.

The maximum water depth of the main body of the Sound is about 22 feet, although because of the extensive shoals around the margin and projecting into the sound, the mean depth is not more than 15 feet.

Brant Island Shoal and Middle Ground Shoal extend parallel from the mouth of Pamlico River approximately 16 miles in a southeasterly direction, reaching mid-sound. Bluff Shoal (approximately 13 miles long) completely divides the sound extending from the mainland on the north to marginal shoals located around Ocracoke Inlet. Extensive shoal areas are found bordering the shoreline; the water depth over the shoals ranges from 2 to 10 feet. The bottom type in the shoal areas is generally sand and sand-mud combinations. Bottom sediments in the deeper areas are composed of sand, clay, mud, or various combinations of these base materials.

The salinity in Pamlico Sound is usually between 15 to 24 ppt, and will normally not vary more than plus or minus 5 ppt for any given area. There is little lunar tide within the Sound; the periodic tide range is less than one half a foot (Parsons, Brickerhoff, Hall and Macdonald, 1954). Therefore, differences in salinity, resulting from tidal action are usually small except near the inlets.

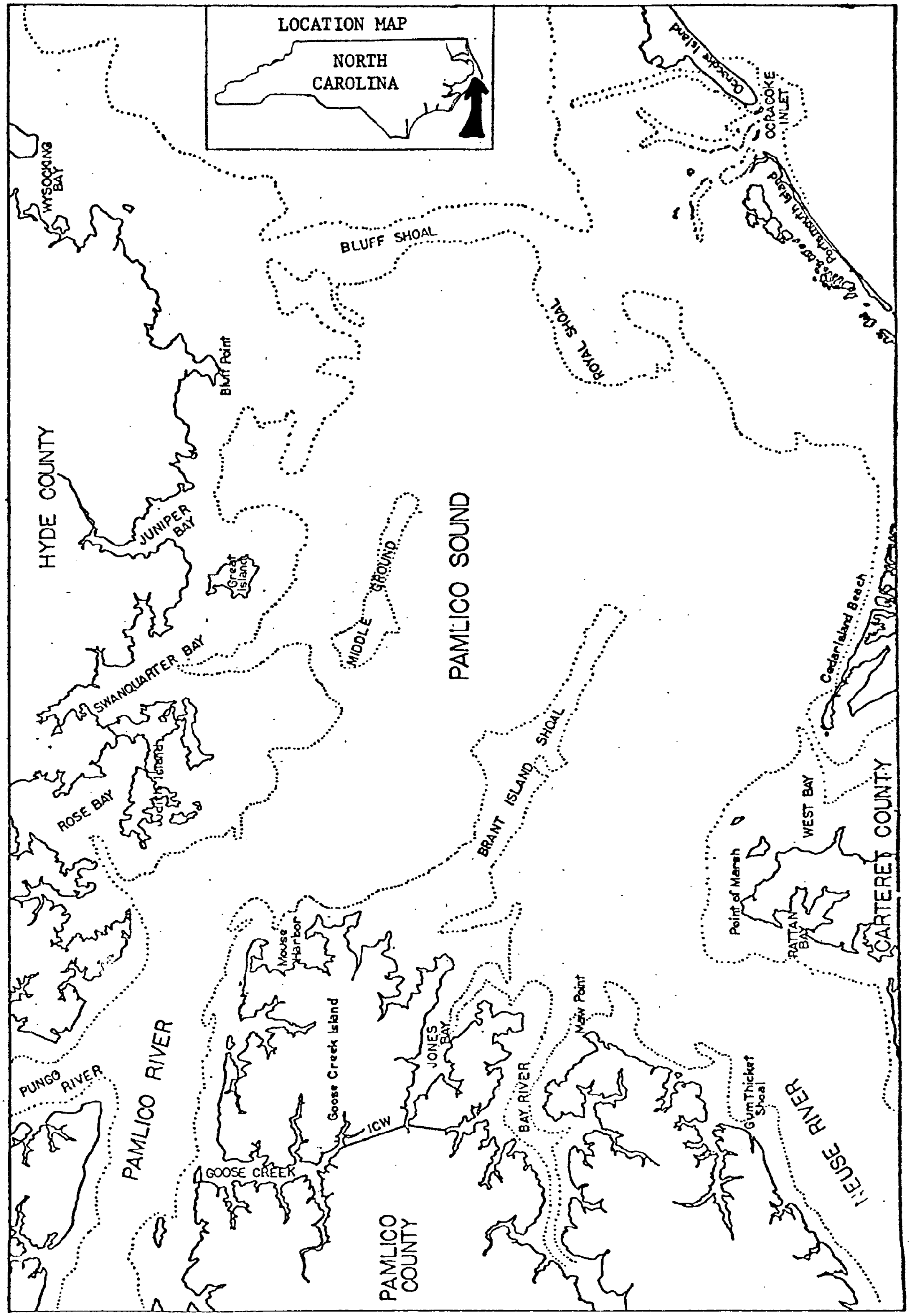

Figure 1.--Pamlico Sound, North Carolina's largest estuary

The wind driven tides in Pamlico Sound seldom vary more than two feet above and below the normal water level (U.S. Dept. of Commerce, 1973). Prevailing winds are from the southwest and produce a lower tide than a northeast wind.

Cedar Island Beach and the Middle Ground area of Pamlico Sound posed the greatest problem with mixed catches and were therefore selected for concentrated sampling (Figure 1).

COLLECTION OF SHRIMP

Data were obtained aboard the Division vessel RALEIGH BAY captained by personnel with commercial fishing backgrounds and considerable shrimping experience. The vessel was equipped with a single 50-foot otter trawl constructed of 3/4 inch bar mesh.

Species composition and length-frequency distribution data were obtained from samples. Salinity and water temperature data were also recorded. All tows were timed to permit determination of catch/effort values.

Samples were taken at night and during daylight hours in order to compare catch/effort data for management scheme considerations.

RESULTS AND DISCUSSION

This report includes pink and brown shrimp discard data obtained during fall, 1976 and spring, 1977 in Pamlico Sound. Shrimp were not available during November due to early cold fronts which forced water temperature into the low teens ($^{\circ}$C). Winter shrimping observations in Pamlico Sound reveal that water temperatures of 15°C or higher are necessary for the shrimp to be out of the substrate; active, feeding, and available to fishing gear.

Shrimp remaining at the end of the fall season spend the winter burrowed in the substrate, and this overwintering segment supports the spring pink shrimp fishery in Pamlico Sound. Movement is not stimulated until rising water temperatures occur in the spring. The severe cold weather which gripped the United States this winter had a damaging effect on stocks of overwintering pink shrimp in Pamlico Sound. Sampling effort in excess of 15 hours during April and May produced only three individual pink shrimp. There were no commercial catches of pink shrimp reported from Pamlico Sound during the spring, 1977. It is apparent that the near-total mortality of the spring segment of the pink shrimp population may be attributed to extreme winter conditions.

Length-frequency distribution of pink and brown shrimp and a summary of catch composition, number per pound, pink-brown ratio, and percent discard are presented in Tables 1-3.

Length-frequency distribution modes of pink shrimp remained in the 95 mm and 105 mm total length groups throughout the sampling period (Table 1). Apparently this condition of modal equilibrium is caused by constant recruitment of juvenile shrimp, a continuing fishing effort on the larger individuals within the population, and no migration from Pamlico Sound. Catch-effort data presented in Table 2 further supports evidence of continuous recruitment. Catch-per-unit-of-effort (CPUE) did not decrease with time, but instead, a slight increase was observed. Results of sampling during the fall of 1975 indicated this same condition of modal equilibrium and an increased CPUE.

Daylight samples contained insignificant numbers of pink shrimp, even under turbid water conditions, indicating that pink shrimp are indeed nocturnal and available to the fishery only during the hours of darkness. Catches of brown shrimp were also considerably less during hours of daylight. The highest CPUE recorded for brown shrimp during day sampling was 2.88 lbs per hour, which occurred under rough sea conditions and very turbid water. On the other hand, night catches of brown shrimp reached a high of 10.92 lbs per hour and were consistently higher than day samples. Data presented in Table 2 provide evidence that both pink and brown shrimp were more readily available to the fishery during hours of darkness.

Length-frequency distribution of brown shrimp presented in Table 1 reveals that this was a mature population ranging from 95 mm to 185 mm. Peaks in the length-frequency range give evidence to continuous recruitment of the early juveniles of this population rather than a single period of recruitment. Brown shrimp were available in significant numbers throughout the fall and catch-per-unit-of-effort remained relatively constant. By early October, 31 percent of the total catch still consisted of brown shrimp. Shrimp landings data show that this late fall concentration of large brown shrimp has not been available for several years in Pamlico Sound. When graded, the brown shrimp of 165 to 175 mm total length were 16-20 per pound, headless. Pamlico Sound is unique in that this body of "inside" water is capable of producing such large shrimp.

Discard of total catch varied in Pamlico Sound from 31.59 percent in early September to 25.43 percent late in the month. During the same period, percent discard of pink shrimp (only) varied from 78.78 percent to 51.24 percent (Table 3). It should be noted that pink shrimp length-frequency modal groups shifted from a 95 mm total length group to a 105 mm group by late September giving evidence of growth, thus reducing discards. The lower discard ratios appear to have been caused by the presence of significant numbers of mature brown shrimp and pink shrimp growth. These discard percentages are considerably lower than those reported for fall, 1975.

Table 1.--Length-frequency distribution of pink and brown shrimp obtained during night hours in Pamlico Sound, North Carolina, 1976

PINK SHRIMP

Midpoint of 10 mm size groups[1]

Date	35	45	55	65	75	85	95	105	115	125	135	145
9/1		.4	1.3	4.6	8.4	26.3	37.8	18.9	2.1		.2	
9/7			1.2	3.0	10.6	23.9	32.3	23.5	4.7	.7	.1	
9/12				2.1	5.7	13.7	30.2	33.8	12.8	1.5	.3	
9/20		.2	1.5	1.5	6.7	16.4	24.9	32.3	14.2	2.2		
10/4			.1	1.1	4.5	16.7	23.0	26.2	20.0	7.2	1.3	.1
10/26				1.1	3.9	11.3	19.3	31.1	19.0	10.3	3.6	.4

BROWN SHRIMP

Midpoint of 10 mm size groups[1]

Date	75	85	95	105	115	125	135	145	155	165	175	185
9/1				.3	4.5	24.3	27.7	9.8	22.9	9.1	1.3	
9/7			.1		3.8	17.7	21.7	17.0	22.2	15.9	1.4	.1
9/12				.6	4.7	20.9	22.2	16.5	18.9	12.9	3.3	
9/20					2.7	26.2	23.3	18.4	18.9	8.3	2.0	.2
10/4					4.4	23.7	21.6	18.5	18.9	10.5	2.4	
10/26	.7	5.2	12.4	22.9	15.9	15.9	11.8	4.6	6.5	2.6	2.0	

[1]Percent of total number of size groups (total length mm). All shrimp in size groups less than 105 mm (70-per-pound, headless) are considered pre-commercial.

Table 2.--Comparison of day/night catch effort of pink and brown shrimp in Pamlico Sound, North Carolina, 1976

PINK SHRIMP

	DAY					NIGHT				
	Mean water		Total	Number		Mean water		Total	Number	
Date	Temp. (°C)	Sal. (PPT)	number caught	shrimp sampled	CPUE (lb/hr)[1]	Temp. (°C)	Sal. (PPT)	number caught	shrimp sampled	CPUE (lb/hr)[1]
9/1	23	22	110	110	.22	23	22	579	476	1.17
9/7	23	19	23	23	.09	23	19	1,455	765	2.36
9/12	23	19	94	94	.37	23	19	1,304	752	2.24
9/20	22	19	101	101	.53	22	19	1,509	402	5.86
10/4	23	22	73	73	.37	23	22	2,526	921	4.48
10/26	16	18	0			16	18	1,289	700	3.10

BROWN SHRIMP

	DAY					NIGHT				
	Mean water		Total	Number		Mean water		Total	Number	
Date	Temp. (°C)	Sal. (PPT)	number caught	shrimp sampled	CPUE (lb/hr)[1]	Temp. (°C)	Sal. (PPT)	number caught	shrimp sampled	CPUE (lb/hr)[1]
9/1	23	22	435	282	2.77	23	22	1,266	711	8.03
9/7	23	19	162	162	2.88	23	19	1,639	869	10.92
9/12	23	19	208	136	2.51	23	19	1,294	814	6.96
9/20	22	19	71	71	1.07	22	19	926	408	10.57
10/4	23	22	29	29	.53	23	22	1,156	742	6.84
10/26	16	18	0			16	18	153	153	.62

[1]Heads on

Table 3.--Summary of catch composition, count, pink-brown ratio, percent discard and catch per unit of effort, data obtained in Pamlico Sound, North Carolina 1976

	Percent Composition of catch by species		Count (no/lb headless)		Pink-brown ratio	Percent discard by number		CPUE (lb/hr)		
Date	pink	brown	pink	brown	(number)	pink-brown catch	pink only	Total catch	pink	brown
9/1	31.4	68.6	113	36	1:2.2	31.59	78.78	9.20	1.17	8.03
9/7	47.0	53.0	123	30	1:1.1	33.29	70.98	13.28	2.36	10.92
9/12	50.2	49.8	103	33	1:1.0	24.84	51.72	9.20	2.24	6.96
9/20	62.0	38.0	103	35	1:0.6	25.43	51.24	16.43	5.86	10.57
10/4	69.0	31.0	100	30	1:0.5	25.07	45.27	11.32	4.48	6.84
10/26	89.4	10.6	95	56	1:0.1	32.47	35.57	3.72	3.10	.62

II. Economic

Introduction

The essence of the pink shrimp discard problem is a choice between present and future income. Harvesting brown shrimp when pre-commercially sized pink shrimp are destroyed and discarded in the harvesting process reduces the stock of pink shrimp available for capture in the late fall and spring fishing seasons. This reduction in stock size implies a lower expected quantity of future pink shrimp landings than would occur if discard did not exist. Hence, discarding juvenile pink shrimp represents a sacrifice of future income. However, a management strategy designed to protect immature pink shrimp from being discarded implies a loss of present income if adoption of the policy results in a reduction in commercially sized brown shrimp landings. Clearly, the decision maker must weigh the reduction in present income against the potential increase in future income that would result from adopting a particular management strategy.

The objectives of the economic portion of the pink shrimp discard study are:

(1) to specify an economic framework within which alternative public policy actions concerning pink shrimp discard can be evaluated; and

(2) to estimate the expected net economic gains to be realized by the North Carolina shrimp fishery if selected management strategies were to be adopted.

The basic bioeconomic model was proposed in the last report. The method of analysis was to establish an accounting equation that can be easily used to evaluate the benefits and costs of any discard policy considered for implementation.

The focus of this report is on objective (2). In general, it was found that the values of several parameters (e.g. the natural mortality rate and the reduction in brown shrimp landings) in the cost-benefit equation may fluctuate from year to year due to variations in uncontrolled factors, especially weather conditions. Hence, the approach adopted here is to simulate various states of nature, and then compute the benefits and costs associated with each situation.

The Benefit-Cost Equation

A complete evaluation of alternative discard strategies requires the management agency to specify the set of policies and/or combinations of policies to be considered. Then, for each policy, it must identify and quantify the costs imposed upon and the benefits received by the fishery relative to the situation that would prevail if no policy was adopted. Finally, the preferred policy is that for which the difference between total benefits and total costs is greatest. If costs exceed benefits for each policy, the best management strategy is to permit the discard of pre-commercially sized pink shrimp.

The benefit-cost decision rule is to choose the i^{th} policy from among the T (i = 1,2,...,T) policies being considered that maximizes the difference between benefits, B_i, and costs, C_i.

Maximize[1] $B_i - C_i$ for $B_i - C_i > 0$

where

$$B_i = (Q_o K^B d_o - Q_i K^B d_i)(\frac{W^F}{K^F})(\frac{P^F}{Z^F}) + (Q_o K^B d_o - Q_i K^B d_i)(\frac{W^S}{K^S})(\frac{P^S}{Z^S}) + \Delta S_i + \Delta V_i^B$$

and $C_i = (P_o^A Q_o - P_i^A Q_i) + \Delta E_i + \Delta V_i^C$

[1]The variables used in the equations are defined:

o denotes the "no policy" alternative

i = 1,2,...,T represents the values of variables when the i^{th} policy is in effect.

There are three sources of costs to be considered before implementing a discard policy. These include the value of foregone landings of commercially sized shrimp, administrative and enforcement costs, and any increase in vessel operating costs as a result of the policy's regulations.

The primary cost component is the value of the reduction in landings forces upon the fishery by the policy's restrictions on shrimping activity, $P^A_o Q_o - P^A_i Q_i$. It is important to note that the relevant cost is the <u>value</u> of commercially sized shrimp <u>not</u> landed during the discard period <u>that would have been landed</u> had the policy not been adopted. Since value is the product of price and quantity landed, changes in both of these terms should be considered.

Quantity landed can be viewed as a technical relationship between the fish stock and the amounts of economic inputs employed by the industry. For a given population size, factors such as the number and size of vessels in the fleet, the type of gear used, the number of hours fished per day, and weather all influence industry landings.

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d = discard rate = <u>number</u> of juvenile shrimp ÷ <u>number</u> of marketable sized shrimp.

Q = quantity of commercially sized shrimp landed at the time of discard.

K^B = number per pound of brown shrimp landed

W = a composite term, representing the effects of growth and mortality on the juvenile pink shrimp saved from discard. It is used to determine the expected landings in each future period and the number per pound. (W^F = fall, W^S = spring)

K^F, K^S represent the size of pink shrimp landed in the fall and spring.

P^A, P^F, P^S represent the average price per pound of brown shrimp landed during the discard period, P^A, the price of pink shrimp in the fall, P^F, and the price of pink shrimp in the spring, P^S.

Z^F, Z^S = discount factor indicating that \$1.00 of present income is preferred to \$1.00 of future income.

Each discard policy will affect this technical relationship so as to reduce the quantities of both commercially and pre-commercially sized shrimp that are landed. For example, increasing the minimum legal mesh size may reduce the quantity of juvenile pink shrimp landed and discarded, but it will also permit more commercially sized shrimp to escape. Prohibiting night shrimping would virtually eliminate the discard problem except at sunrise and sunset. However, if the environmental factors are such that brown shrimp are also feeding at night, this policy would virtually eliminate the brown shrimp fishery as well as the pink shrimp discard.

The impact that particular policies will have on brown shrimp landings is not known. However, this study examines its importance in the benefit-cost equation by assuming several levels for the reduction in brown shrimp landings.

It has already been stated that the value of the reduction in brown shrimp landings can be decomposed into a change in landings and a change in the price per pound received by fishermen. A well-known economic phenomenon asserts that a decrease in the quantity landed can be expected to cause an increase in price per pound. Thus, changes in price vary inversely with changes in landings, and tend to minimize the cost of adopting a discard policy.

In general, the greater is the increase in price per pound, for a given reduction in landings, the lower will be the total cost of any policy. This results because, although fewer pounds of brown shrimp are landed, each pound landed receives a higher price. Alternatively, the smaller is the unit price increase, for a given reduction in landings, the greater will be the cost of adopting a discard policy.

To illustrate the importance of this conclusion, consider the following example. For simplicity, assume that during the discard period, 200,000 pounds of shrimp will be landed if no policy is adopted, and 100,000 pounds if policy i is implemented. Initially, assume that price per pound rises from \$2.25 to \$2.50. Then, assume that price per pound does not rise. The value of the reduction in shrimp landings is computed from the expression

$$C = P_o^A Q_o - P_i^A Q_i .$$

Case 1: Price rises to \$2.50/lb.

$$C = (2.25)(200,000) - (2.50)(100,000)$$

$$C = \$200,000$$

Case 2: Price does not rise

$$C = (2.25)(200,000) - (2.25)(100,000)$$

$$C = \$225,000$$

The value of the reduction in shrimp landings is greater in Case 2 (no price rise) than in Case 1. The rise in price partially offset the reduction in value. With no price change, the harvest value was reduced by \$225,000. In contrast, if price increases to \$2.50 per pound, the reduced value of harvest is \$200,000.

Considerable effort has been devoted to determining the relationship between changes in quantity landed and changes in price per pound.[2]

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[2] As indicated in the text, it is necessary to have an estimate of the change in exvessel price due to a given change in landings. Economic theory suggests that this information can be determined by formulating the exvessel demand and estimating the values of its parameters.

In general, the exvessel demand for shrimp is derived from the wholesale and retail demands for shrimp. In addition, there is a demand for North Carolina shrimp to be shipped to other producing and/or consuming centers.

It was hypothesized that current price is a function of current landings, but landings themselves are a function of preceding prices. Hence, the quantity supplied is unresponsive to current market price, and ordinary least squares estimation techniques may be employed. However, current price does influence the willingness of shrimpers to fish in future periods.

The estimated demand equation is

$$\ln P_t = -3.43842 - \underset{(-3.4335^{**})}{.00014856Q_t} - \underset{(-4.8700^{***})}{.0077915_{t-1}} + \underset{(2.3343^{*})}{.00904Y_t}$$

$R^2 = .75$

$n = 52$

$$- \underset{(-2.2608^{**})}{.01168Z_t} + \underset{(3.2089^{**})}{.01203B_t} - \underset{(-.4096)}{.00129F_t}$$

where P = average exvessel price for size 4150 in North Carolina, deflated by the CPI (\$/lb.)

To summarize the results, it was hypothesized that a key feature of shrimp price determination is that producing regions are interrelated by product flows. Price differentials between markets provide incentives for dealers and brokers to move shrimp in search of the highest price. Whenever prices, less transportation costs, rise above those paid in other states, shrimp will flow into North Carolina. This tends to negate the original price increase.

A reduction in North Carolina landings due to the adoption of a discard policy is expected to have a small impact on price as shrimp flows into North Carolina from other regions. In fact, it is estimated that a 10% reduction in North Carolina landings will increase exvessel prices by .3%.[3]

Q = total quantity landed, regardless of size, in North Carolina (1000 lbs.)

S_{t-1} = beginning stocks of shrimp held in cold storage in the U.S. (million lbs.)

Y = per capita deflated U.S. income ($/person)

Z = quantity of shrimp landed in other Southeastern and Gulf states (million lbs.)

B = Consumer Price Index for beef products

F = Consumer Price Index for food fish

Monthly data (May-November) for the period 1969-1975 were used.

All coefficients, except that of the price of food fish, were significantly different from zero at the 5% confidence level and demonstrated the expected sign. T values are shown within parentheses.

The extremely small coefficient on the North Carolina landings variable suggests one of two possible explanations. First, North Carolina is a small producer of shrimp relative to total U.S. production and a given change in landings may be insignificant relative to total shrimp production. Second, there may be a simultaneity bias in the estimated coefficient if the supply of shrimp landed is influenced by current market price. Although it may be true that current price does not influence current quantities landed, the relevant market period appears to be a week. Since monthly data were used, each observation includes more than one market period.

[3] To determine the predicted impact on the price of shrimp in North Carolina due to a change in quantity landed, one must transform the price equation. First, let

$$A = -3.43842 - .007791S_{t-1} + .00904Y - .01168Z + .01203B - .00129F.$$

Then, $P = e^{-.00014856Q}e^{A}$.

The change in price due to a 1000 pound reduction in quantity landed is

$$\frac{dP}{dQ} = -.00014856e^{-.00014856Q}e^{A}.$$

Hence, a given policy induced reduction in landings will stimulate a negligible increase in price per pound. This has the effect of maximizing total cost for a given quantity reduction, and reduces the chance that benefits will exceed costs.

Increased enforcement and administrative costs, ΔE_i, include the expense of employing new enforcement officers and equipment, if needed, and any additional wage payments to existing officers to compensate them for the time required to fulfill their additional duties. Another enforcement cost is the increased value of damage inflicted on other species because officers devote relatively less of their time to these species, and hence do not detect violations that they would otherwise have detected.

The effect of discard policies on vessel operating cost in the summer, ΔV_i^C, is not known. In general, the enforcement and operating cost components are assumed to be small relative to the cost in terms of foregone landings.

Since A includes the values of all variables included in the equation, it is easier to work in percentage changes. Thus, the percentage change in price due to a given percentage change in quantity landed is defined

$$\frac{\%dP}{\%dQ} \simeq \frac{dP}{dQ}\frac{Q}{P} = \frac{[-.00014856e^{-.00014856Q}{}_eA]Q}{e^{-.00014856Q}{}_eA}$$

$$\frac{dP}{dQ}\frac{Q}{P} = -.00014856Q$$

This percentage change includes the value of Q, and hence will vary over time as quantity landed varies. In the simulated examples presented later, the initial level of landings is assumed to be 200,000 pounds. Hence the percentage reduction in price is

$$\frac{dP}{dQ}\frac{Q}{P} = -.00014856(200) = -.0297 \simeq 3\%$$

There are four sources of benefits to be estimated when evaluating a discard policy. The primary benefit is the increased value of commercially sized pink shrimp expected to be landed in the late fall. The remaining sources of benefits include the increased value of commercially sized pink shrimp expected to be landed in the spring, the increased value of commercially sized shrimp expected to be landed in future years, and any decrease in vessel operating costs in the late fall and spring as a result of larger shrimp stocks.

As mentioned above, any policy that protects juvenile pink shrimp from being landed, killed, and discarded increases the stock of shrimp available for capture in the future. However, not all of the juvenile pink shrimp that are saved from discard will be landed in the future. Some will die due to disease or predation. Others will survive to spawn, thus increasing the stock of shrimp in future years. It is important to emphasize that benefits are only derived from those shrimp that are landed, or which reproduce second or third generation shrimp which are landed.

One cannot directly observe the increase in fall and spring pink shrimp landings at the time the management decision is made. Rather, one must first estimate the number of pink shrimp that would be saved from discard if a particular policy was to be adopted. Then, by incorporating into the model the biological processes of growth and mortality, one can estimate the number of these shrimp that can be expected to be landed, week by week, in the late fall and spring seasons.

The total number of juvenile pink shrimp that can be saved from discard by adopting the i^{th} policy is computed as

$$(Q_o K^B d_o - Q_i K^B d_i)$$

where the o subscript denotes the "no policy" action

and Q_o, Q_i = pounds of brown shrimp,

K^B = number of brown shrimp per pound,

d_o, d_i = number of pink shrimp per brown shrimp.

The second term of the expression is necessary if pink shrimp discard is not completely eliminated.

Pinks that are saved from discard are available later in the fall. However, early in the fall pink season, landings are concentrated in the smaller sizes. They mature as the season progresses, and command higher prices as they achieve larger sizes. However, the stock (in numbers) available for harvest at any time throughout this season is declining due to both natural and fishing mortalities. Hence, estimating the proportion of these shrimp in any time period that will actually be landed introduces into the analysis the dynamic processes of shrimp growth and mortality. We have chosen to estimate expected future landings on a week-to-week basis.

Mortality rates are estimated by week from the following equations:

$$\text{Natural mortality rate} = 1-e^{-x}$$

$$\underline{\text{Fishing mortality rate} = 1-e^{-m}}$$

$$\text{Total mortality} = 1-e^{-(x+m)}$$

The total mortality rate is used to determine the number of pink shrimp that survive from one weekly interval to the next. The fishing mortality rate determines the number of shrimp that can be expected to be landed in any particular week.

Over time, the surviving members grow in weight and value. One needs pink shrimp growth rates before a price can be placed on the expected increase in landings. Growth rates provide information on when individual shrimp achieve the next larger size, and hence, when the (higher) price for that size should be used in the valuation process.

The effects of mortality and growth are summarized with the variables W^F (fall) and W^S (spring) of the benefit-cost equation. For the purposes of this study, the increase in landings that may be realized in future years because some pink shrimp may survive and spawn is not evaluated. It is assumed that the environment is the primary determinant of year-to-year fluctuations in the stock of shrimp, and that the impact on future landings of a larger breeding population is negligible and can be ignored.

The effect of discard policies on vessel operating costs in the late fall and spring is not known. Conceptually, a larger population size would increase population density and make both locating and landing shrimp less time consuming, and hence less costly.

Application of the Model

The purpose of this section is to illustrate the use of the benefit-cost equation. The method of analysis will be to hypothesize several situations, and then compute the benefits and costs associated with each case. The values of the variables used in the computations conform as closely as possible to those actually observed. However, hypothetical values are used when data is not available. The values of all parameters will be varied to provide information on the sensitivity of the benefit-cost outcome to changes in the parameters. As we learn more about the sizes of the parameters involved, simulations can be more narrowly defined to approximate actual situations. Those costs and benefits not included here might also be estimated and included.

All of the calculations that follow explicitly consider only the expected value of increased future pink shrimp landings and the value of reduced brown shrimp landings. These are the largest and most visible (to fishermen) benefit and cost components. All other sources of benefits and costs are assumed to be negligible. However, the management agency will want to keep in mind that these additional benefits and costs do exist, whatever their magnitude.

As already discussed, the chief cost component of a discard policy is the value of the reduction of brown shrimp landings due to the enforcement of a discard policy. Three levels of policy induced brown shrimp landings are hypothesized. Landings could be slightly diminished, reduced by approximately one-half, or greatly decreased. Each of these situations could occur with the prohibition of night shrimping. Sampling during the fall season, 1976, revealed that nearly 85% (5125 of 6001) of the brown shrimp were landed at night. Although the implied costs are greater than would be the case if, say 50%, had been landed at night, the benefits are also greater since a larger number of pink shrimp will be saved from discard. Hence one cannot expect a policy solely on information of costs or benefits alone. Both are required.

The benefits of a discard policy are more difficult to quantify because of the dynamics of shrimp growth and mortality and because there are several factors which influence the expected quantity of future landings. The peak discard period is assumed to occur in early September. Pink shrimp saved from discard are specified to be 95mm in length and are hypothesized to be available to the fishery until early November (for about 8 weeks)and then again in the spring (for 6 weeks).

Estimating the expected increase in future pink shrimp landings is not an easy task. For a given quantity of shrimp saved from discard, future pink landings depend on natural and fishing mortality rates, the size of pinks at the time of discard, and the length of the fishing season.

For example, assume that N = 5,000,000 individual pink shrimp saved from discard survive to be the minimum commercial size of 70 per pound, headless. Then, if the natural mortality rate, x = -.25, and fishing mortality rate, m = -.25, are specified, the expected increase in pink landings in each successive week can be computed. During the first week, $N(1 - e^{-m})$, or 1,105,995 shrimp are expected to be landed. Similarly the number of individuals expected to be available for capture in the second week is

$$N\,[1 - (1 - e^{-(m + x)})] = (.6065)\ N = 3,032,655.$$

The number expected to be landed in the second week is

$$(3,032,655)(1 - e^{-m}) = 670,820\,.$$

If these shrimp are sized 60 per pound, this implies that 11,180 pounds were landed in the second week.

The value of the natural mortality parameter used in most of the situations evaluated in this study, X = -.25, approximates the values estimated for pink and brown shrimp in North Carolina.[4]

Throughout the fall, the survivors among the pink shrimp that were saved from discard grow in length and weight, and hence move into progressively larger size groups. The expected length of shrimp landed in each weekly period from September to November was approximated from the equation

$$\text{males: } l = 27\ (1 - e^{-.217(t + 9.82)})$$

$$\text{females: } l = 34.5(1 - e^{-.188\ (t + 6.93)})$$

Although these equations were estimated from spring pink shrimp growth relationships, they were assumed to be at least approximately correct for

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[4] 1. McCoy, Edward G., Migration, Growth, Mortality of North Carolina Pink and Brown Penaeid Shrimps, Special Scientific Report No. 15, June 1968.

2. McCoy, Edward G., Dynamics of North Carolina Commercial Shrimp Populations, Special Scientific Report No. 21, March 1972.

3. Purvis, Connell E. and Edward G. McCoy, Overwintering Pink Shrimp Penaeus duorarum, in Core and Pamlico Sounds, N.C., Special Scientific Report No. 22, April 1972.

4. Purvis, Connell and E. G. McCoy, Population Dynamics of Brown Shrimp in Pamlico Sound, Special Scientific Report No. 25, January 1974.

the fall as well. Biologists have not been able to estimate curves for the fall due to the confounding effects of water temperature on growth.

Male and female lengths at week t were averaged, and then used to determine the expected number of individuals per pound. Expected pounds of shrimp landed is determined by dividing the number of shrimp landed by the number per pound. The appropriate price is also determined once the expected size of shrimp landed is known. Costs and benefits were evaluated using average prices that prevailed in the fall, 1975.

Simulations

Tables 1-3 present the estimated difference between the expected benefits and costs under various assumptions about the values of the natural and fishing parameters, and the reduction in commercially sized brown shrimp landings brought about by the policy's restrictions on fishing activity. In each case, interest was focused on whether or not the range of observed discard rates is sufficiently large to warrant the adoption of the suggested prohibition of night shrimping.

The discard rates[5] used in these examples were 8:1, 4:1, and 1:1. It is assumed that these discard ratios would be reduced to 2:1, 1:1, and .1:1, respectively. In other words, the policy would reduce, but not completely eliminate the discard of pre-commercially sized pink shrimp.

Table 1 presents the estimated net benefits of the discard policy assuming alternative levels of commercially sized shrimp landings. A one pound reduction in brown shrimp landed will increase both the expected costs and benefits to be realized from this policy. Costs are increased because fewer brown shrimp are landed. Benefits are increased because those pink shrimp that would have been discarded are now able to grow, and perhaps be landed in the future. However, it can be seen that the impact

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[5] Discard rate is expressed as the number of pre-commercially sized shrimp per marketable sized shrimp landed.

TABLE 1

Estimated Net Benefits
for Alternative Brown Shrimp Landings*

Policy Induced Reduction in Brown Shrimp Landings (lbs) (31-35)	Discard Rate** 1:1	4:1	8:1
30,000 (15% reduction)	-$ 11,479	$ 88,389	$238,978
100,00 (50% reduction)	-$164,582	-$ 42,677	$124,642
170,000 (85% reduction)	-$313,515	-$176,645	$ 7,505

*These examples assume that M = -.25, X = -.25, and that pink shrimp are 95 mm in length at time of discard.

**Each column assumes that the discard rate is reduced from 8:1 to 2:1, 4:1 to 1:1, and 1:1 to .1:1.

TABLE 2

Estimated Net Benefits
for Alternative Fishing Mortality Rates*

Instantaneous Fishing Mortality Coefficient	Discard Rate** 1:1	4:1	8:1
M = -.15	-$174,821	-$80,400	$ 49,200
M = -.25	-$164,582	-$42,677	$124,642
M = -.50	-$154,358	-$ 5,000	$170,446

*These examples assume that X = -.25, that pink shrimp are 95 mm in length at time of discard and that brown shrimp (31-35) landings are reduced by 100,000 pounds (50%).

**Each column assumes that the discard rate is reduced from 8:1 to 2:1, 4:1 to 1:1, and 1:1 to .1:1.

TABLE 3

Estimated Net Benefits
For Alternative Natural Mortality Rates*

Instantaneous Natural Mortality Coefficient	Discard Rate** 1:1	4:1	8:1
X = -.15	-$145,321	$27,910	$266,200
X = -.25	-$164,582	-$42,677	$124,642
X = -.50	-$188,000	-$128,773	-$47,890

* These examples assume that M = -.25, that pink shrimp are 95 mm in length at time of discard, and that brown shrimp(31-35) landings are reduced by 100,000 pounds (50%)

** Each column assumes that the discard rate is reduced from 8:1 to 2:1, 4:1 to 1:1, and 1:1 to .1:1.

on costs is greater than that on benefits. In general, the more severe the reduction in brown shrimp landings, the less likely it is that expected benefits will exceed costs.

Sampling results from the fall 1976 season are the only data available on the effects of a prohibition of night shrimping on brown shrimp landings. As noted above, nearly 85% of those brown shrimp caught were landed at night. The third row corresponds to this situation. Although brown shrimp may feed during the day, depending on weather conditions, prohibiting night shrimping when brown shrimp can only be landed at night would most likely result in a large net loss to the fishery.

Table 2 presents the estimated net benefits of the discard policy assuming alternative instantaneous fishing mortality rates. A larger fishing mortality rate tends to increase benefits (relative to a lower rate) since a greater proportion of shrimp available for capture at any instant are landed. Note that as one moves down any column in Table 2, the difference between expected benefits and costs is increased. Thus, the greater the fishing mortality rate, the greater the likelihood that expected benefits will exceed costs.

Table 3 presents the estimated net benefits to the fishery assuming alternative natural mortality rates. In general, the larger the rate of loss due to disease, predation, adverse weather conditions, or a lack of food supply, the lower will be the expected benefits of any policy designed to protect juvenile pink shrimp because relatively fewer of those saved from discard will be available for capture in the future. Moving down any column illustrates this point.

Several attempts have been made to estimate fishing and natural mortality parameters for Pamlico, Core, and Bogue Sounds in North Carolina.[6]

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[6] See Footnote 4.

Only two of nine fishing mortality estimates exceeded a value of -.25. Most were less than -.20, of which three were less than -.10. Thus, the North Carolina shrimp populations appear to exhibit low fishing mortality rates.

The natural mortality estimates range from a low of -.213 to a high of -.431. Although these are not as high as the greatest value assumed - Table 3, Row 3 - they are greater, on average, in magnitude than the level used in the computation of Tables 1 and 2.

In all three tables, a discard rate of 8:1 was great enough to result in a positive difference between benefits and costs of adopting a discard policy. However, it must be emphasized that this is not conclusive evidence that benefits will in fact exceed costs. First, these figures represent expected net benefits. They summarize the net difference between benefits and costs only if the anticipated increase in future landings is at least as great as that which was predicted. Any unforeseen factor that alters the basic premises upon which these predictions were made will result in an actual net benefit that differs from the estimated figure.

Second, other factors not mentioned here may vary. Specifically, Tables 1-3 assume that brown shrimp are graded at 31-35 per pound. If brown shrimp are actually measuring 21-25 per pound, the total costs of any discard policy will be understated, and hence the net benefit figures of Tables 1-3 will be overstated. Since larger shrimp command higher prices, a given reduction in the quantity of brown shrimp landed will represent a greater level of foregone current income.

Finally, Tables 1-3 assume that the pink shrimp saved from discard are 95mm in length. If they were 75mm, there would be a greater time interval between the time of discard and the time when the shrimp saved from discard actually reached commercial size. Hence, a larger percentage would suffer from natural mortality before achieving marketable size.

MANAGEMENT IMPLICATIONS

This study has considered management alternatives directed at a significant biological, economic and social problem which occurs in Pamlico Sound almost every year. In the past, discards of pink shrimp are believed to have been sufficiently high to indicate that considerable future income may have been lost while fishing for brown shrimp.

The situation appears to have changed during 1975 and 1976 when the shrimp supply situation dictated that the market would accept pink shrimp at somewhat smaller sizes than in the past. In addition during 1976, brown shrimp reached larger sizes than they had during the recent past.

Results of this study indicate that, under current supply and price situations, discarding pink shrimp is an acceptable practice up to the level of about eight pink shrimp discarded for each brown shrimp retained, at the sizes considered in this report. Whether higher discards would be economically-acceptable would depend upon changes in vessel operating costs and enforcement costs during the time in question. If market demand were strong, leading to premium prices for large brown shrimp, then higher discards of pink shrimp would be acceptable. However, if brown shrimp prices were weak, it might be best in the long run to protect the small pink shrimp and look for future income from the pink shrimp later in the fall and during the following spring, depending on the total market situation.

Some additional study of the parameters considered in this report is recommended in order to better define the sensitivity of net benefits to these parameters.

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